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Usui et al.

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(54) **SEMICONDUCTOR DEVICE**

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H01L 23/10 (2006.01)
H01L 23/34 (2006.01)
H01L 23/473 (2006.01)
H01L 23/495 (2006.01)
H02M 7/48 (2007.01)
(Continued)

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(58) **Field of Classification Search**

CPC H01L 25/00; H01L 27/0629; H01L 23/34; H01L 23/427; H01L 23/3672; H01L 2224/48195; H01L 23/473
USPC 257/686, 706, 707, 777, 691, 714, 723, 257/724
See application file for complete search history.

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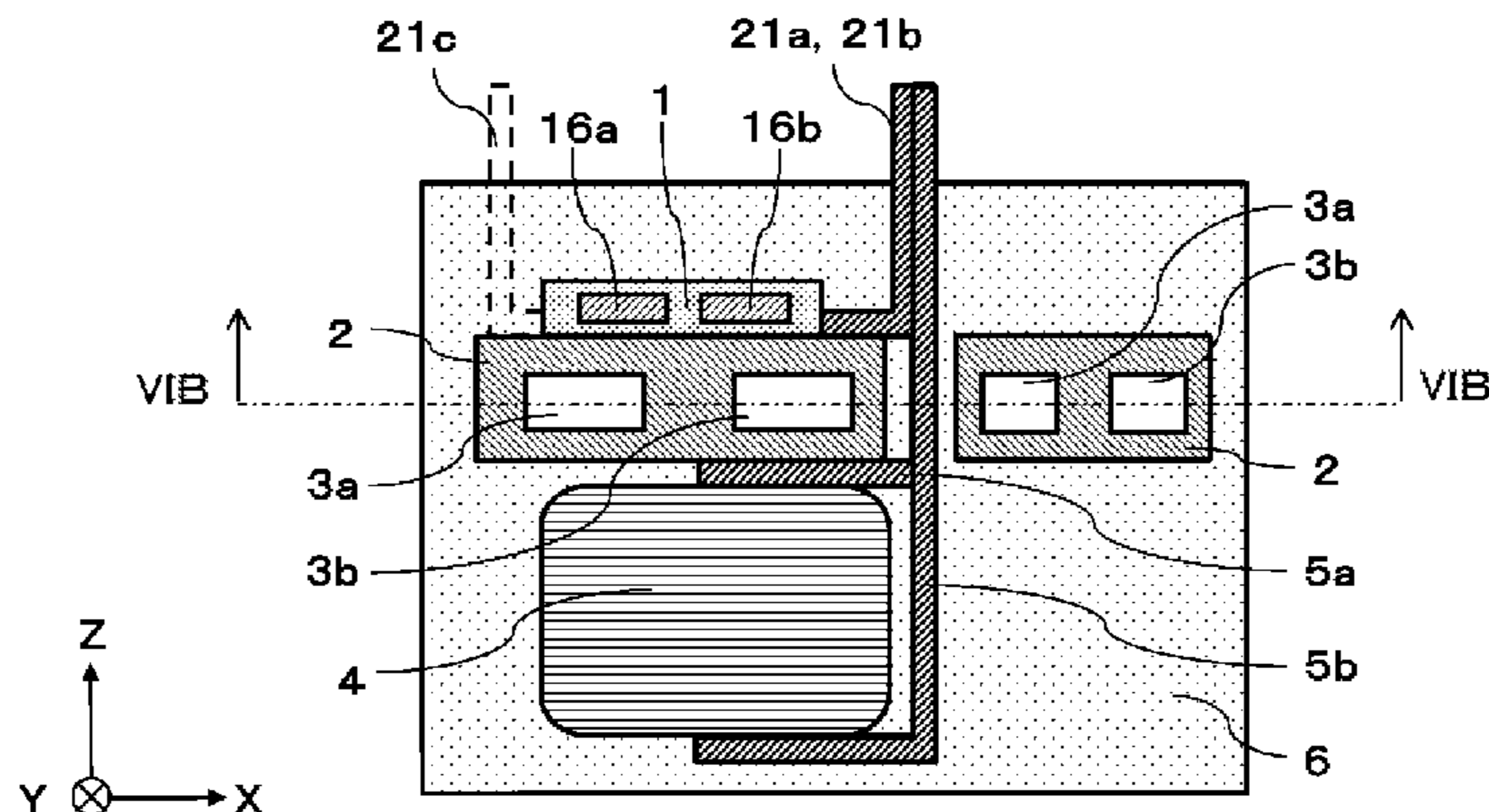
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(57) **ABSTRACT**

A semiconductor device includes a semiconductor module including a semiconductor element, a passive element, a cooling member, a first conductive member and a second conductive member. The cooling member is disposed between the semiconductor module and the passive element. And a first conductive member and a second conductive member electrically connect the semiconductor module and the passive element. Furthermore, two or more aspects of at least one of the first conductive member and the second conductive member face the cooling member.

12 Claims, 22 Drawing Sheets



Related U.S. Application Data

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H01L 23/528 (2006.01)
H01L 49/02 (2006.01)
H05K 7/20 (2006.01)

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FIG. 1A

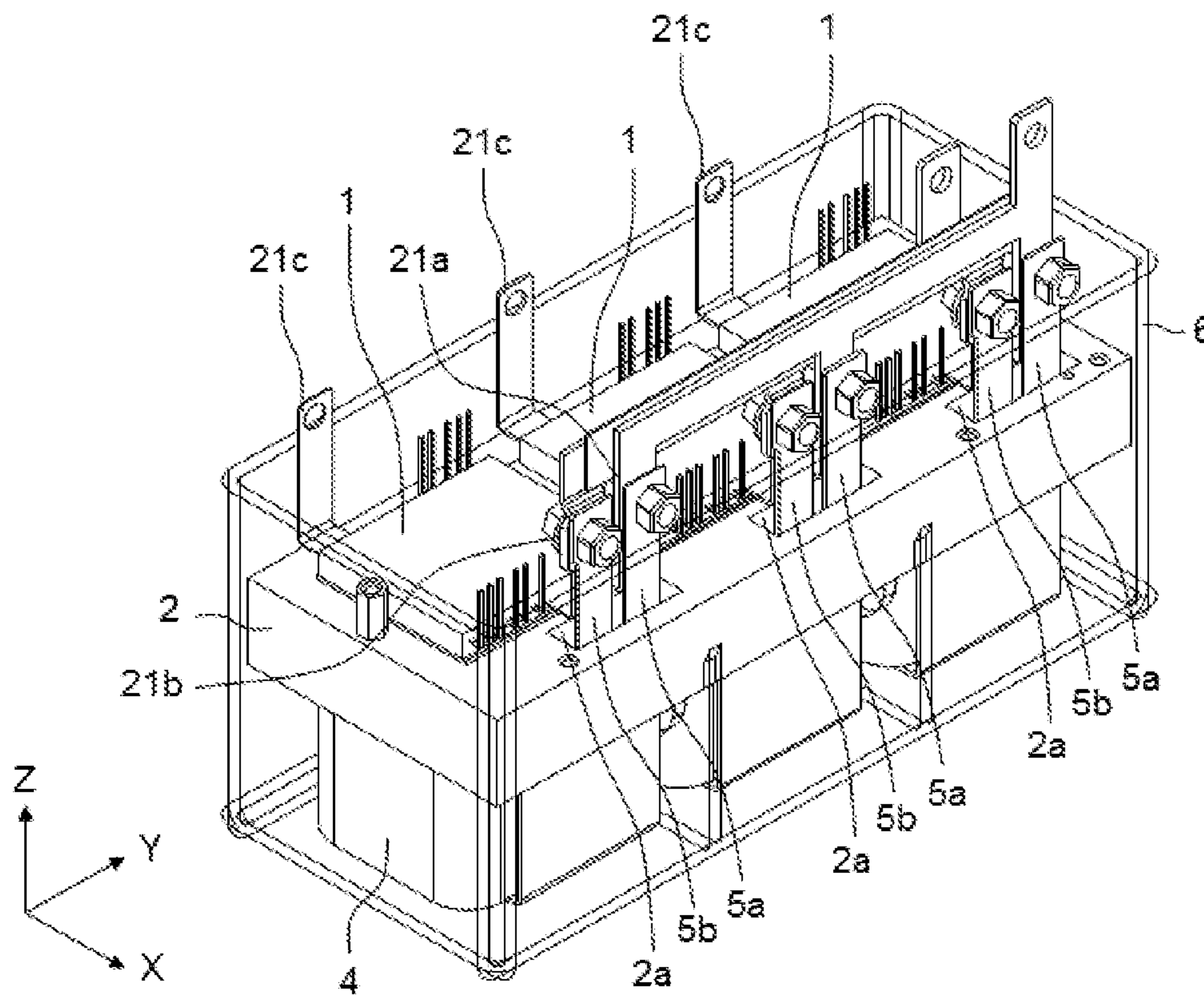


FIG. 1B

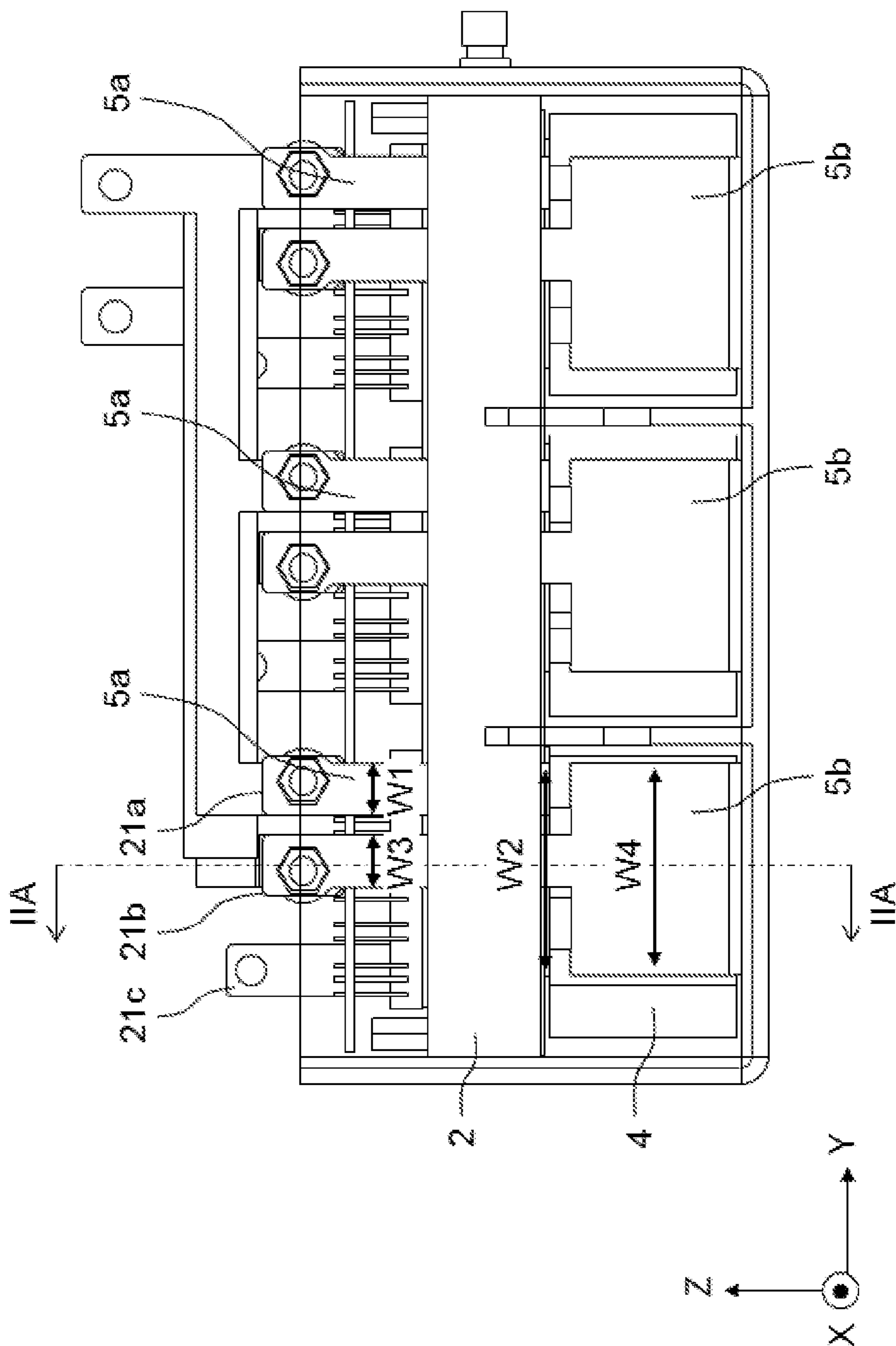


FIG. 1C

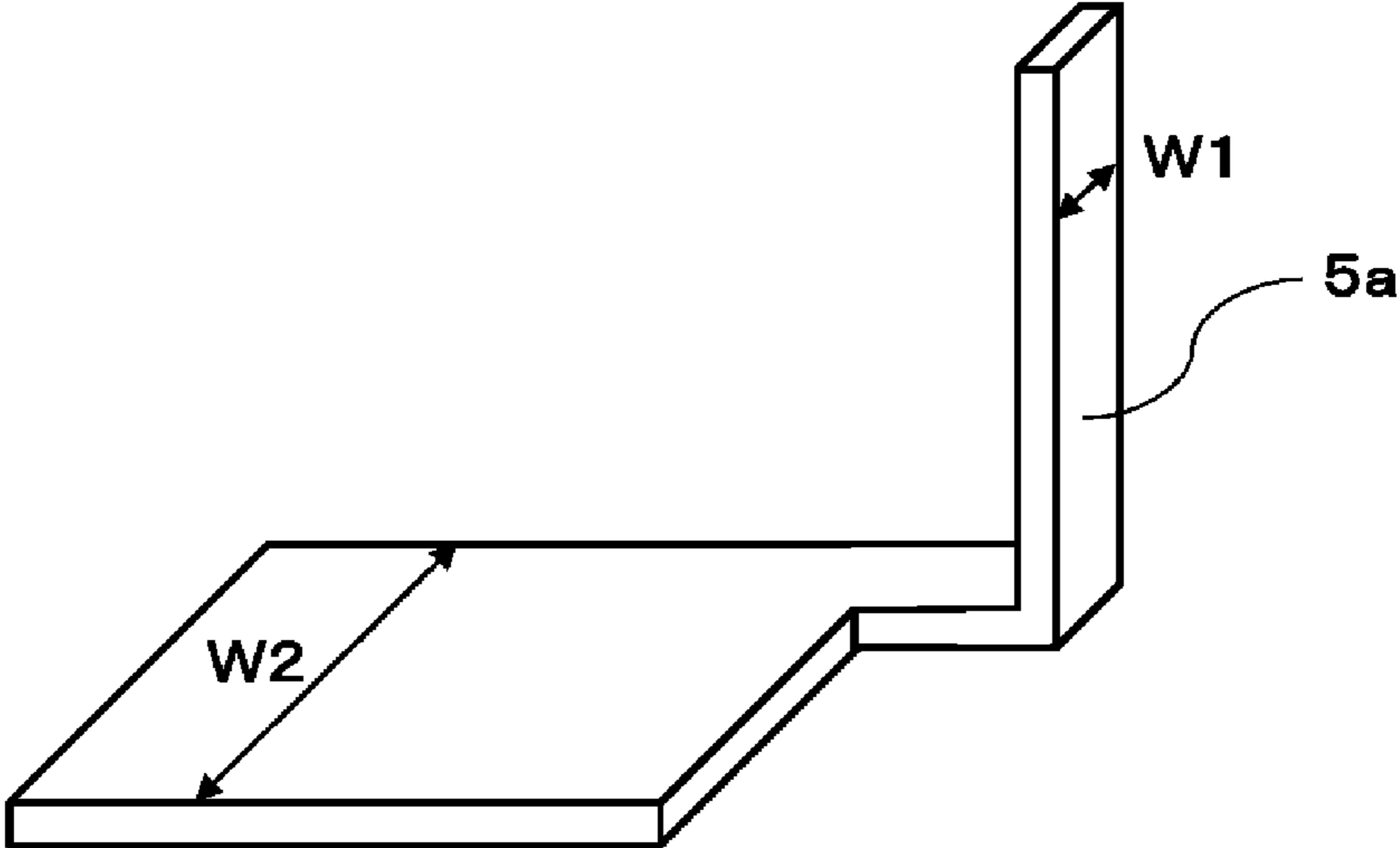


FIG. 1D

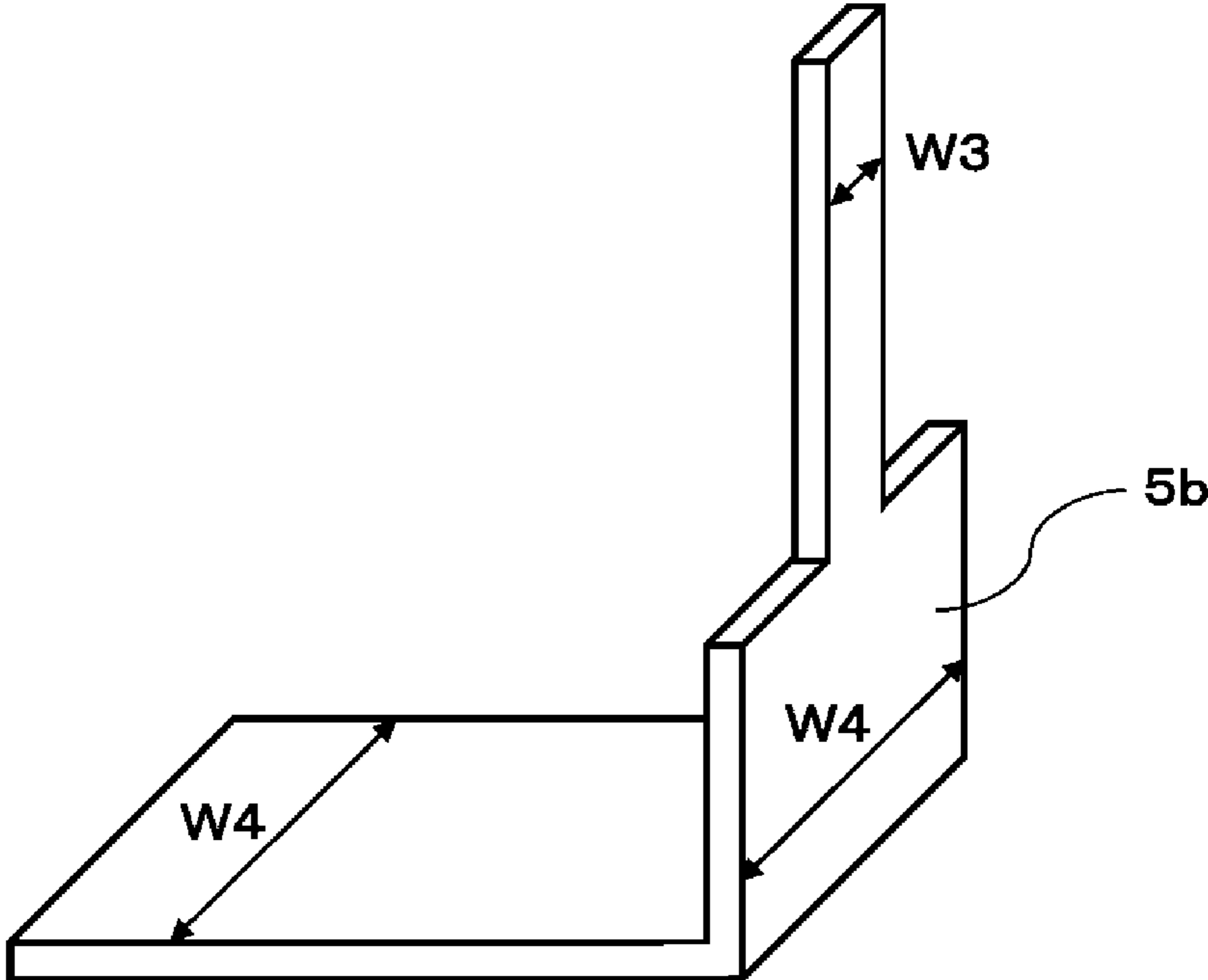


FIG. 2A

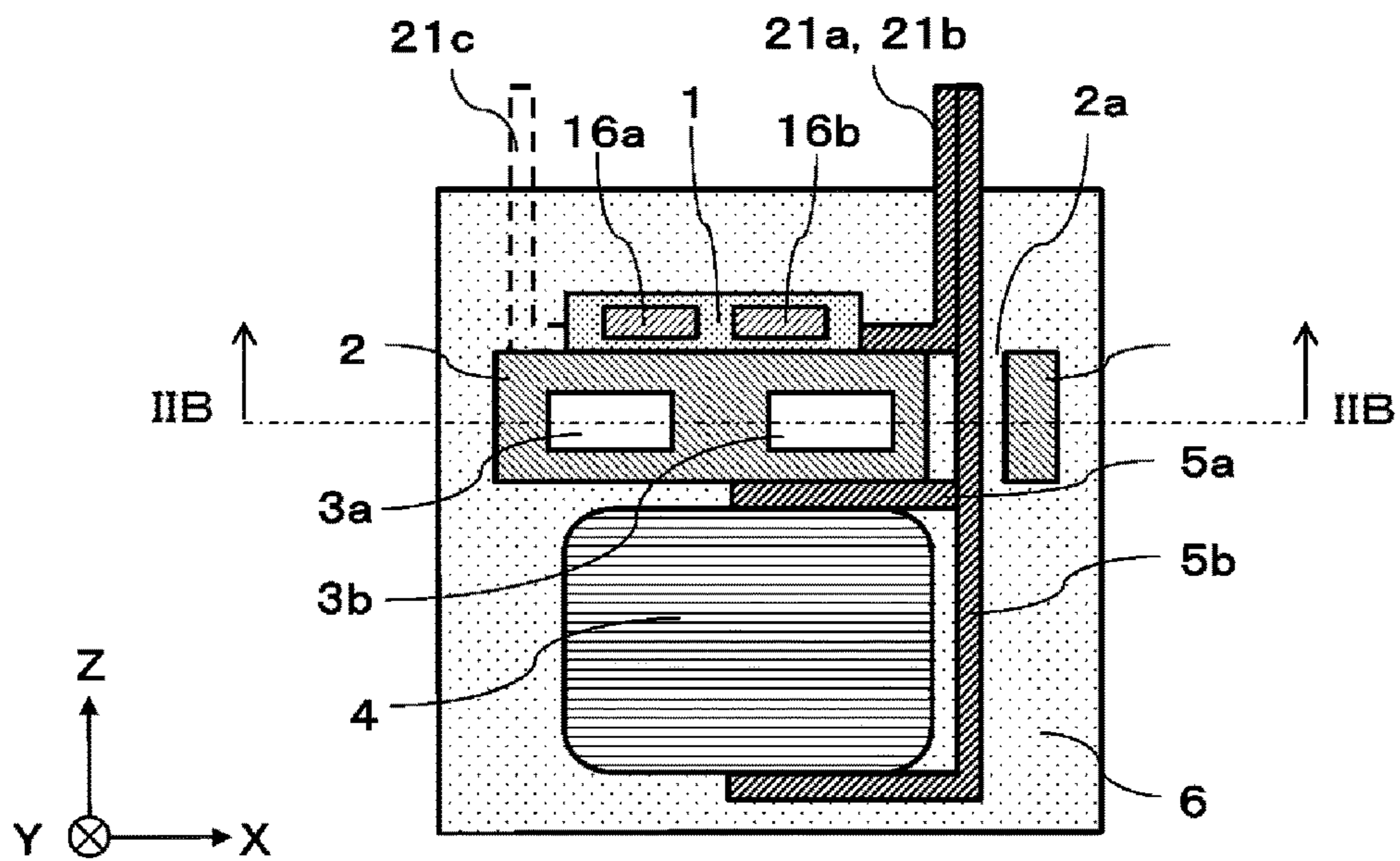


FIG. 2B

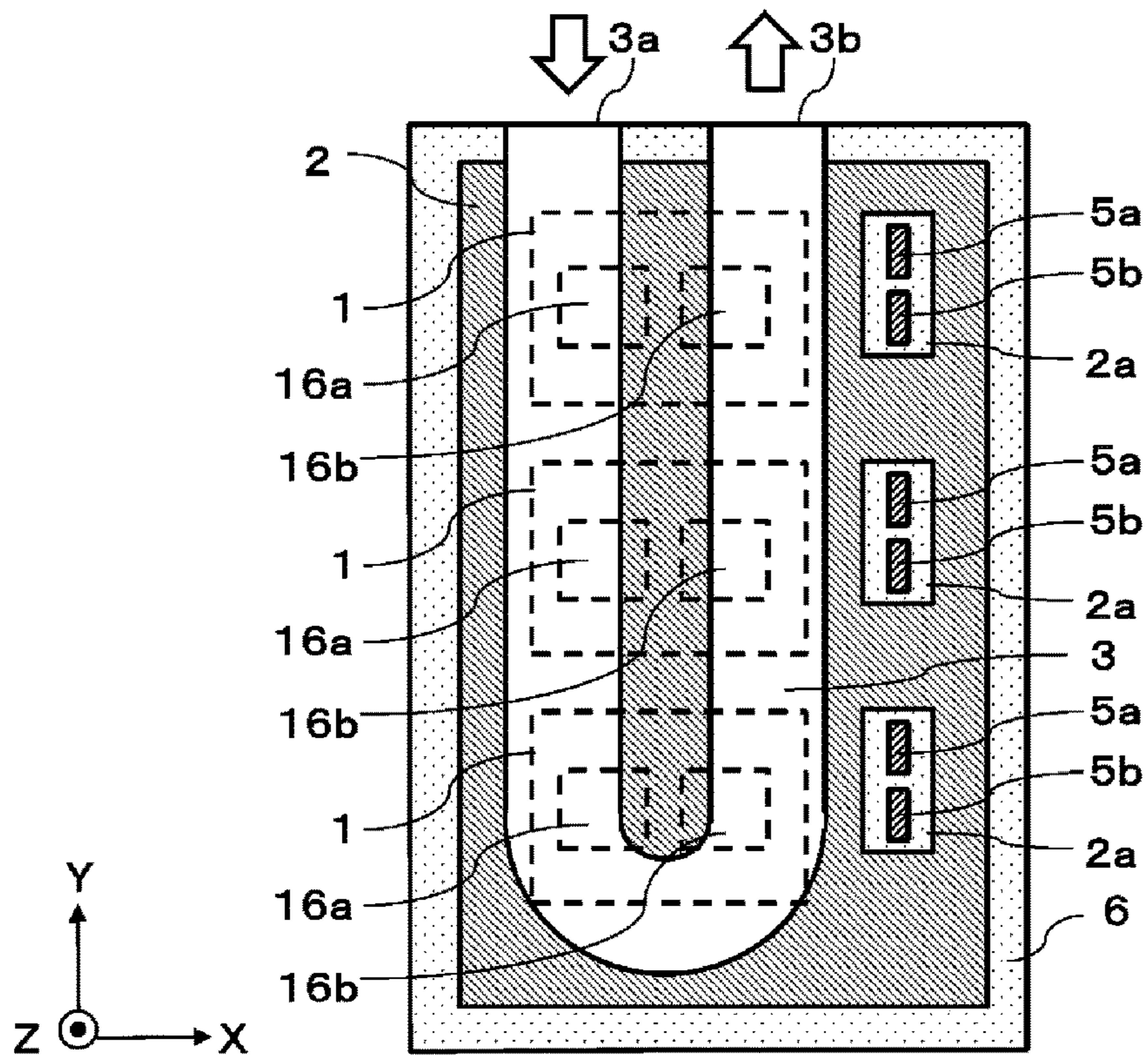


FIG. 3

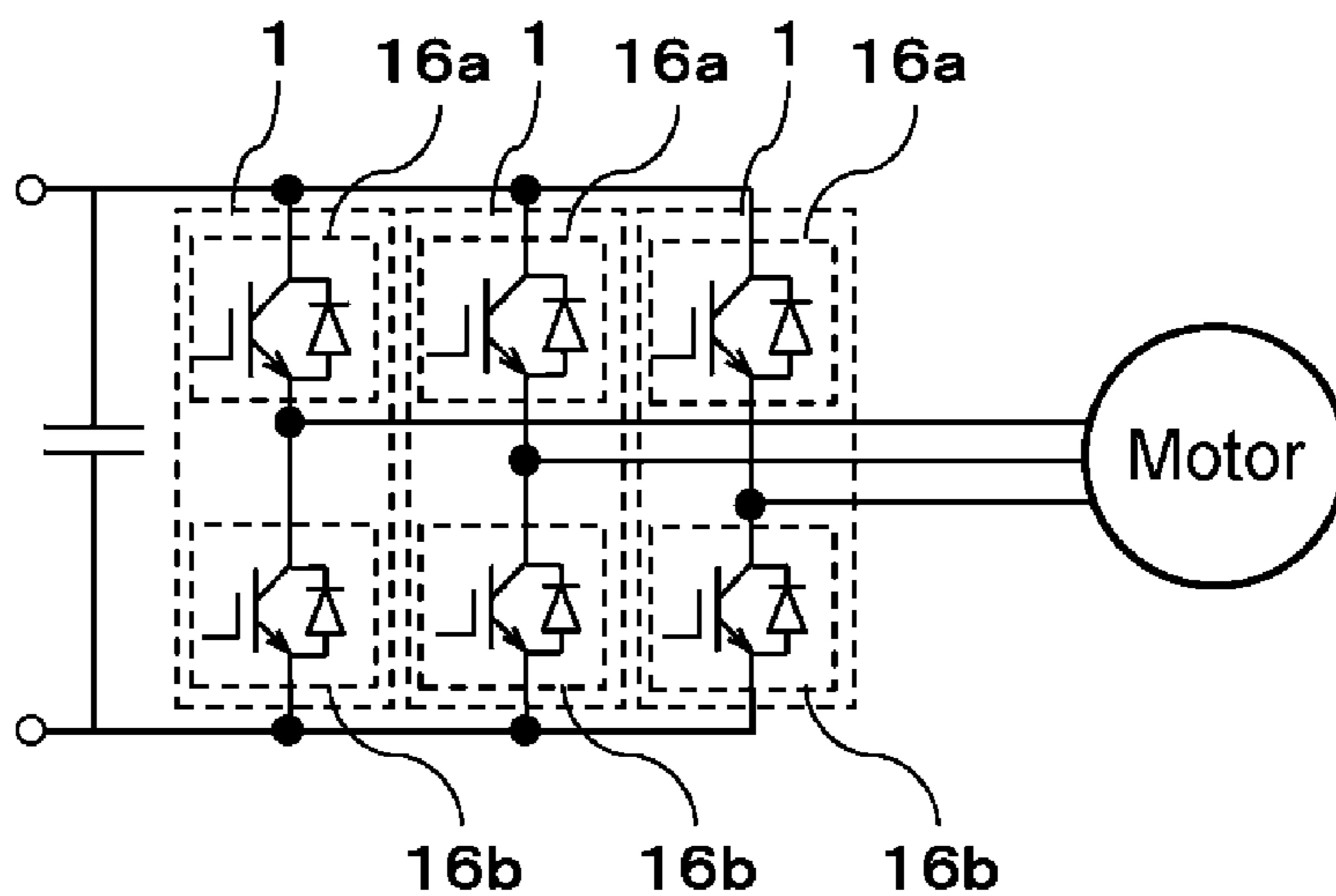


FIG. 4

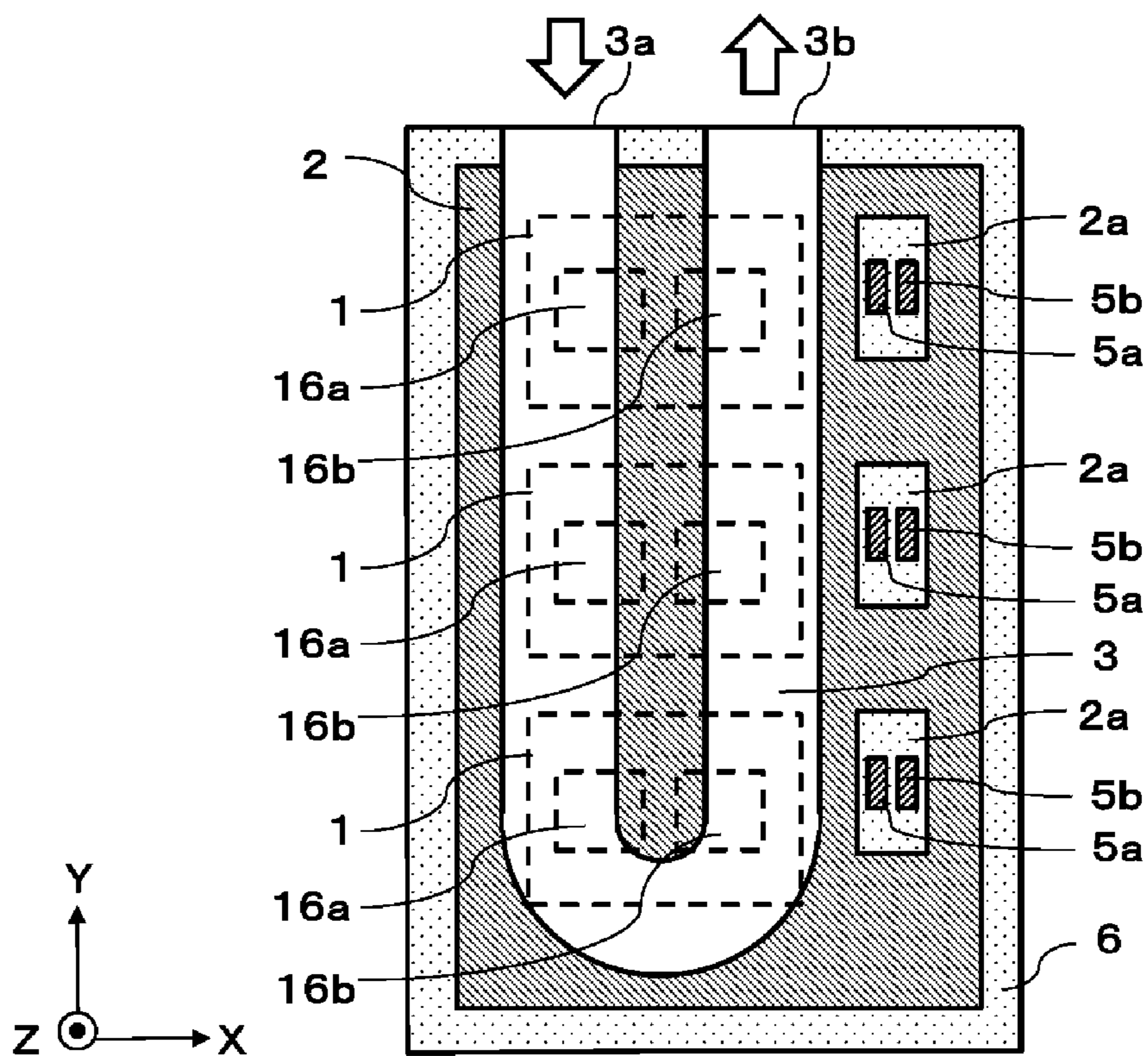


FIG. 5A

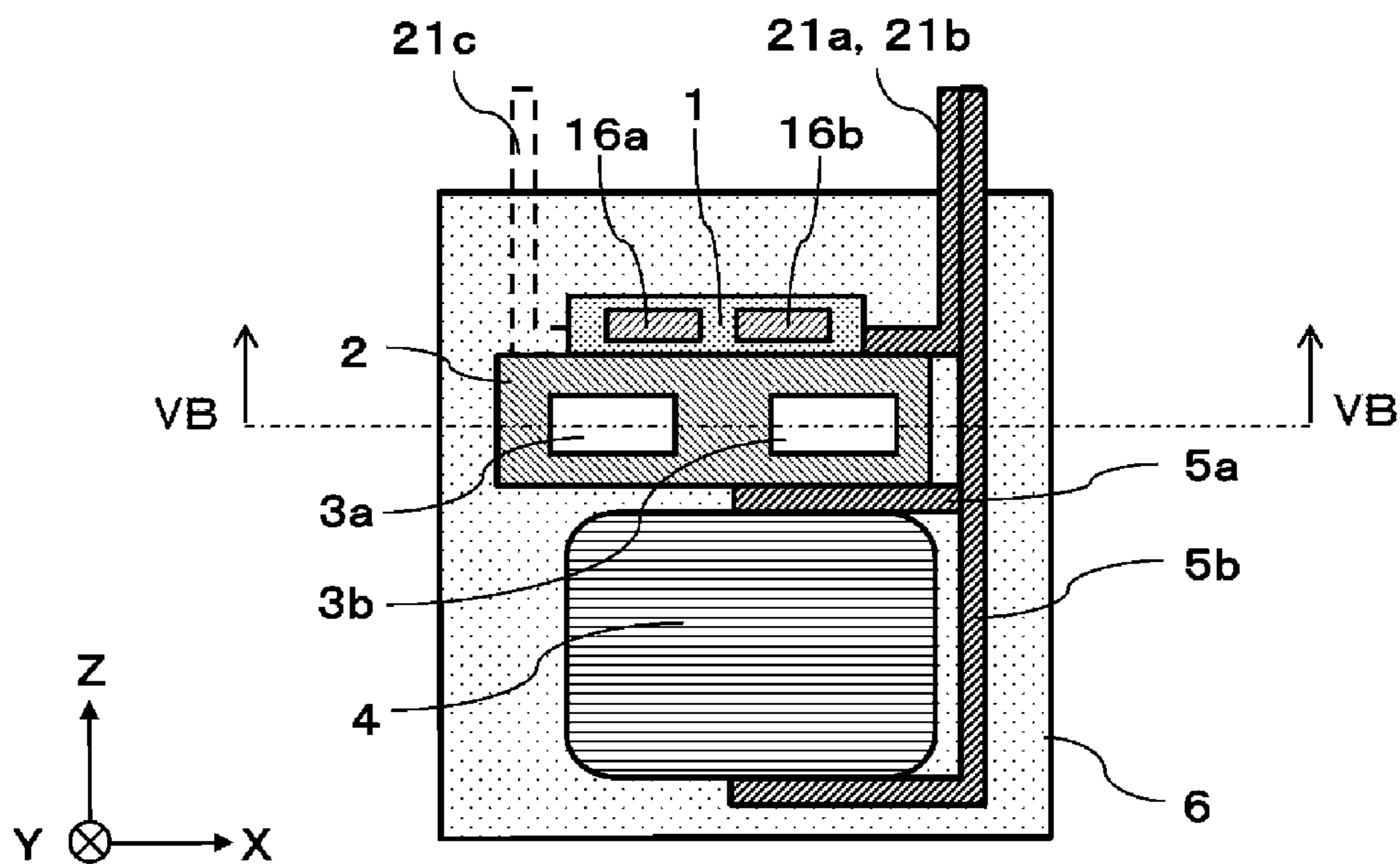


FIG. 5B

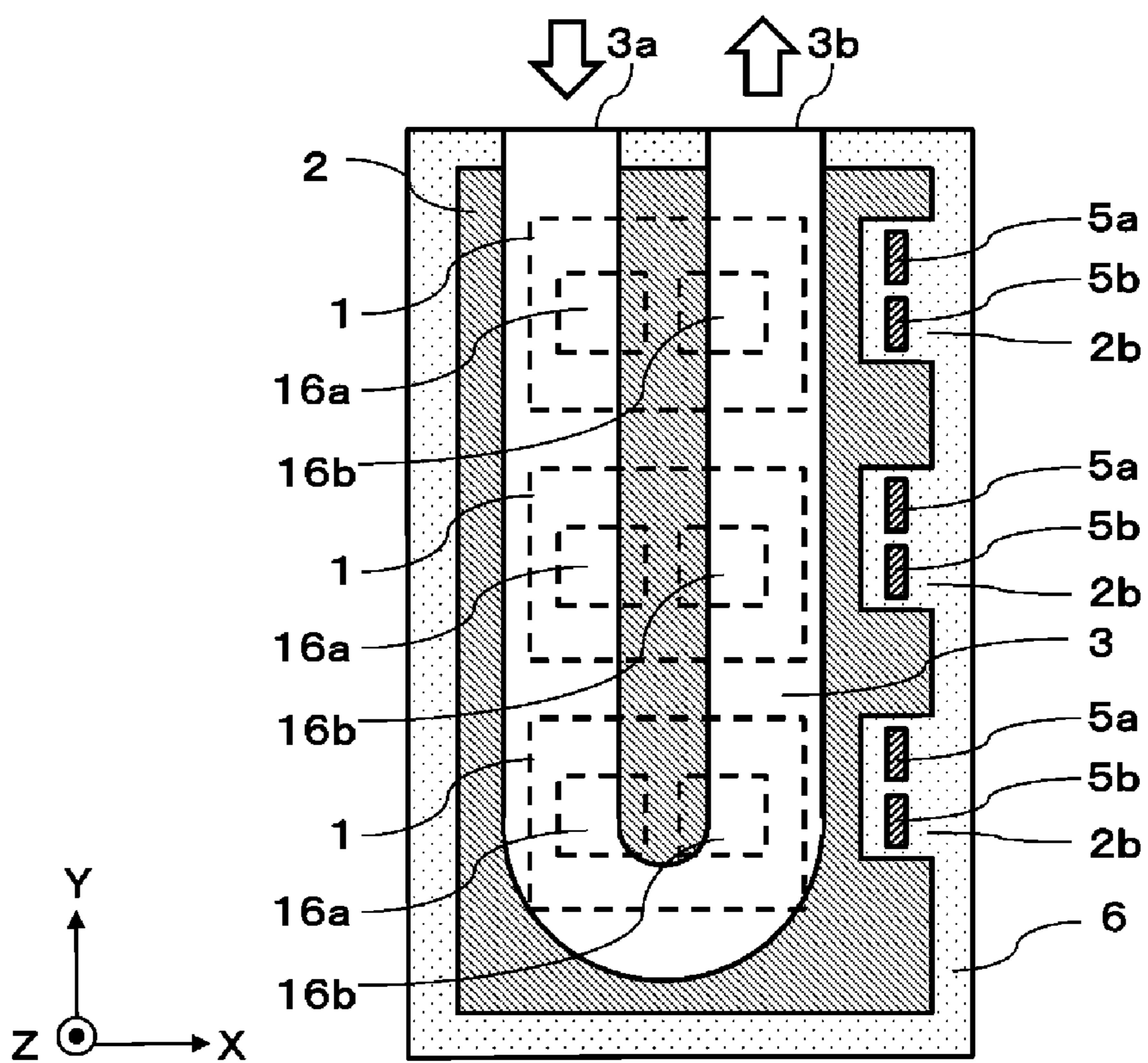


FIG. 6A

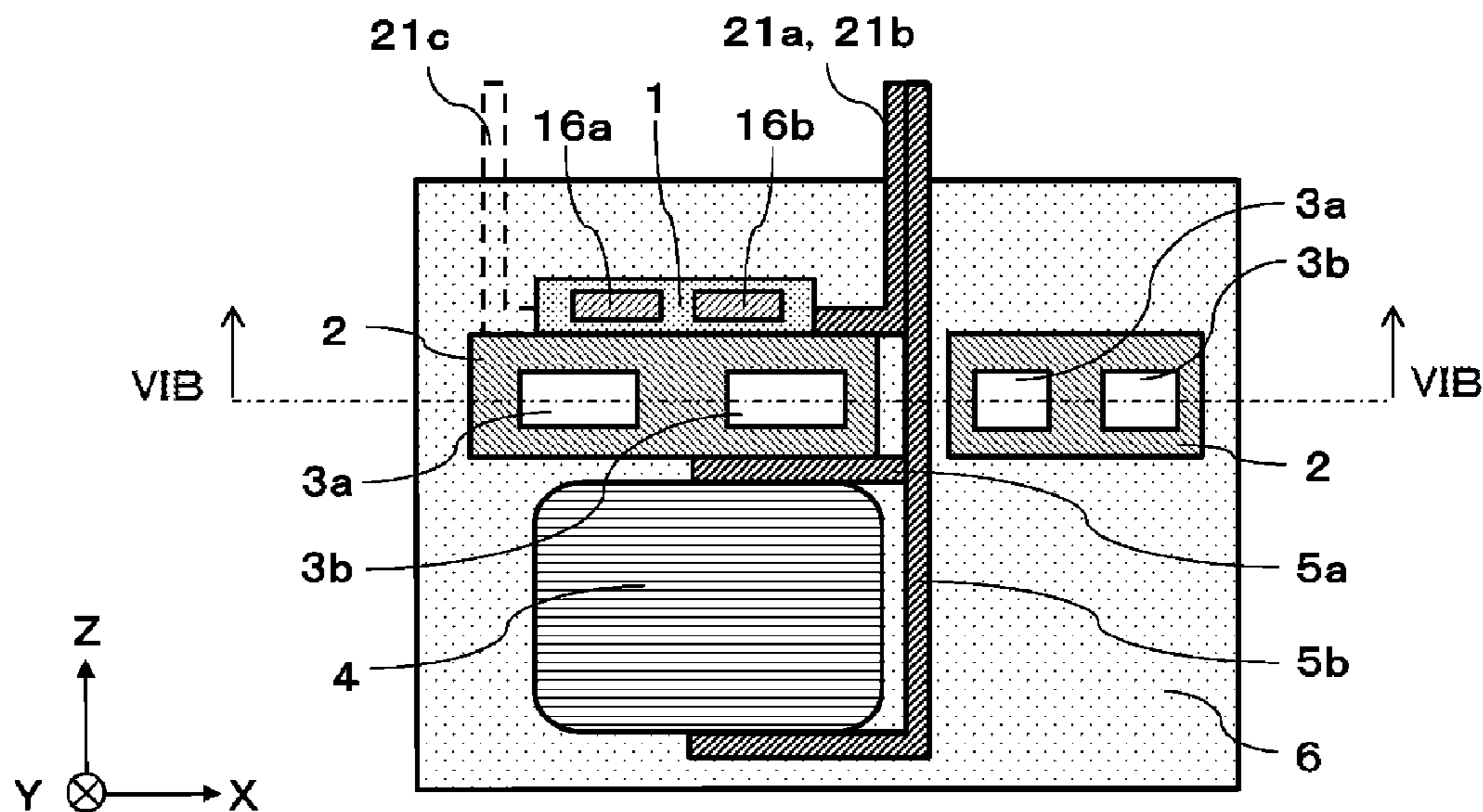


FIG. 6B

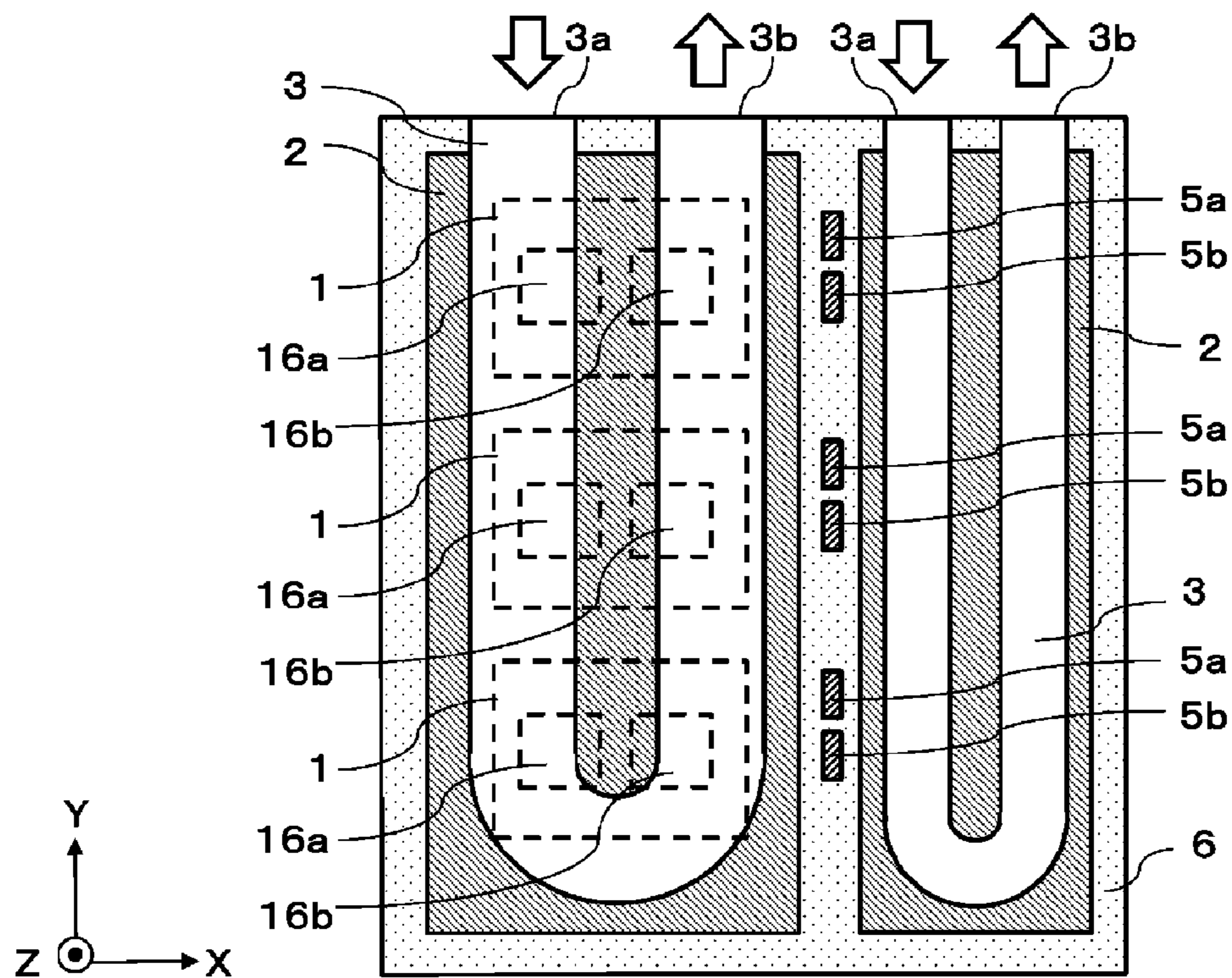


FIG. 7A

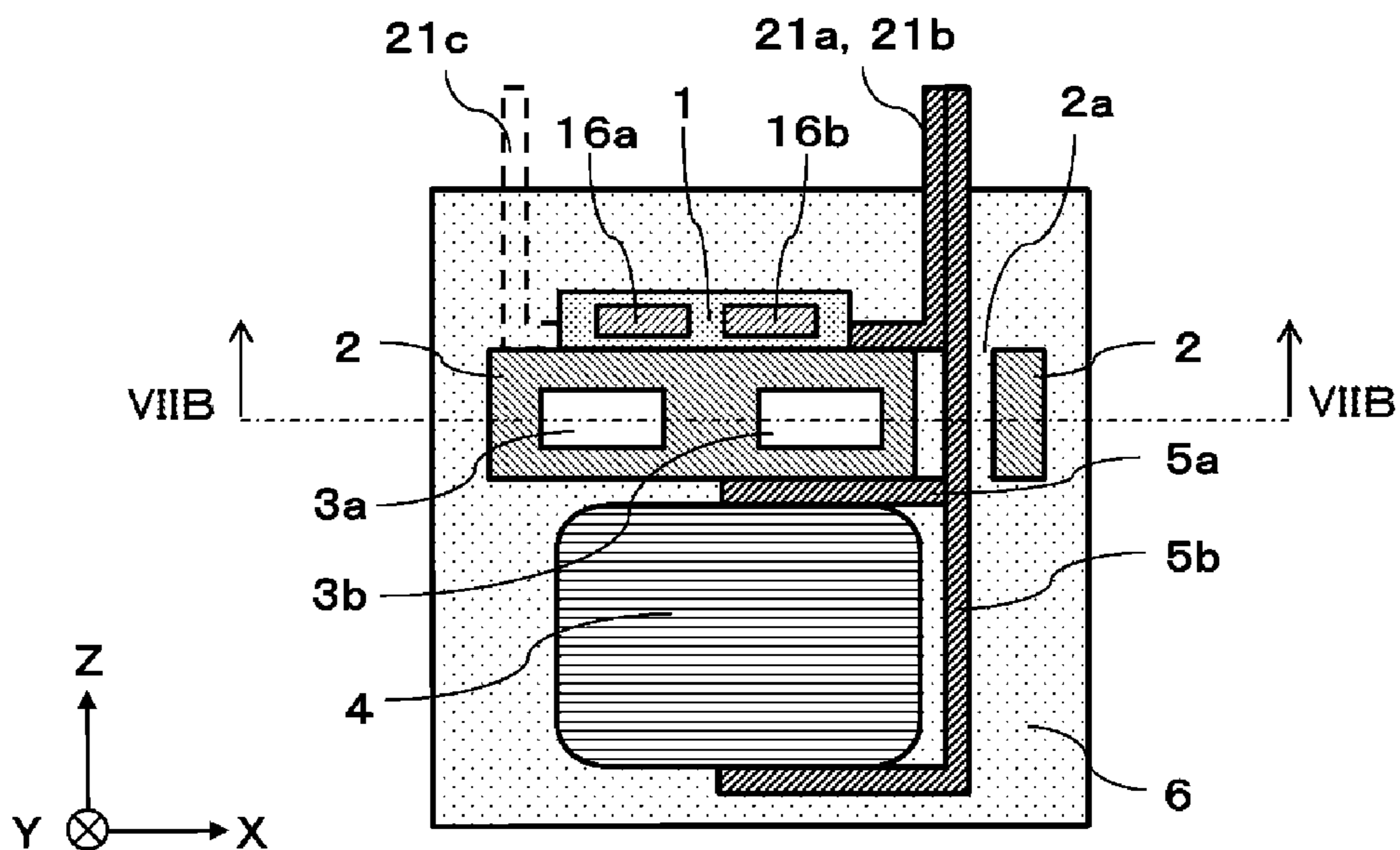


FIG. 7B

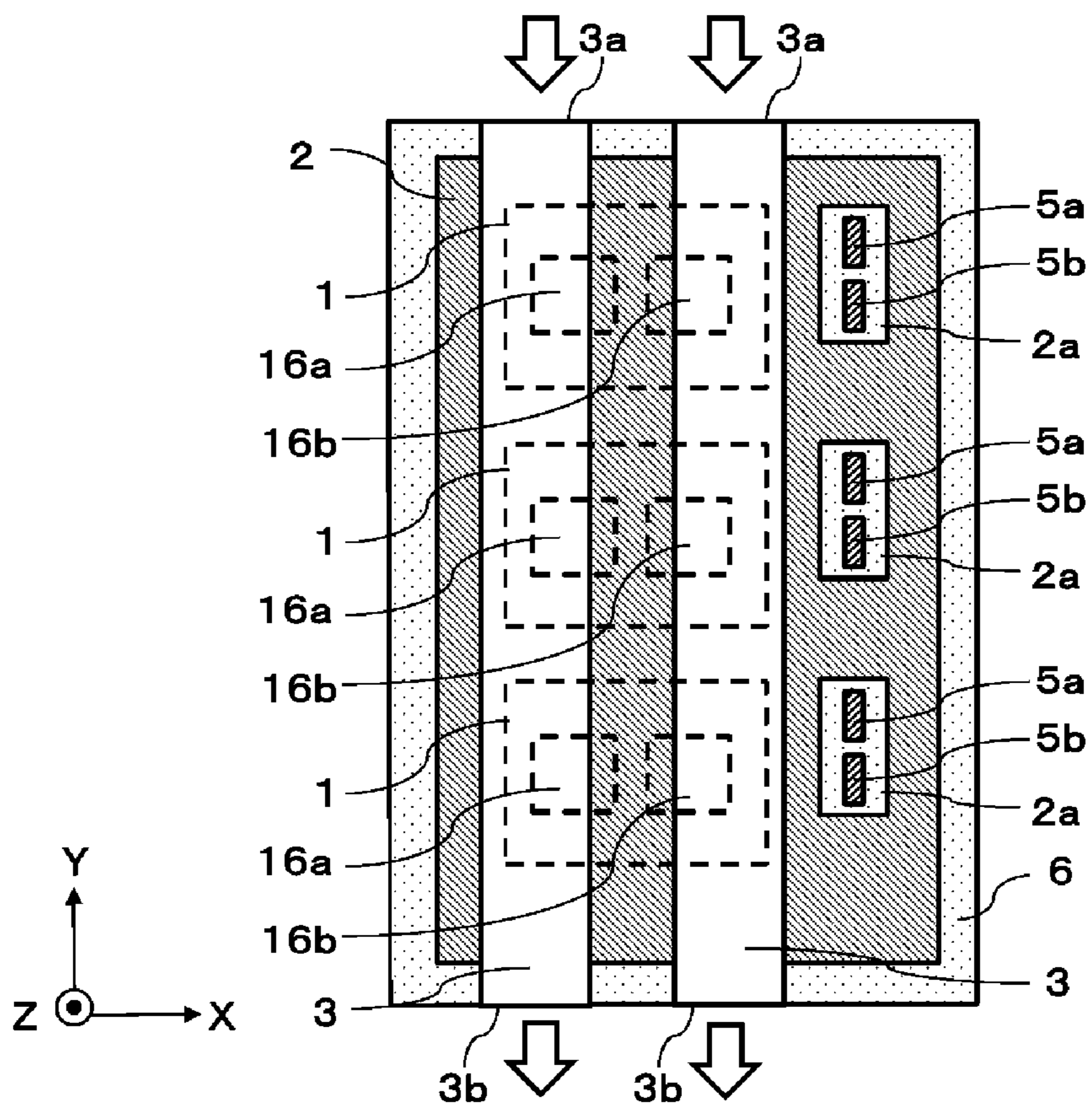


FIG. 8A

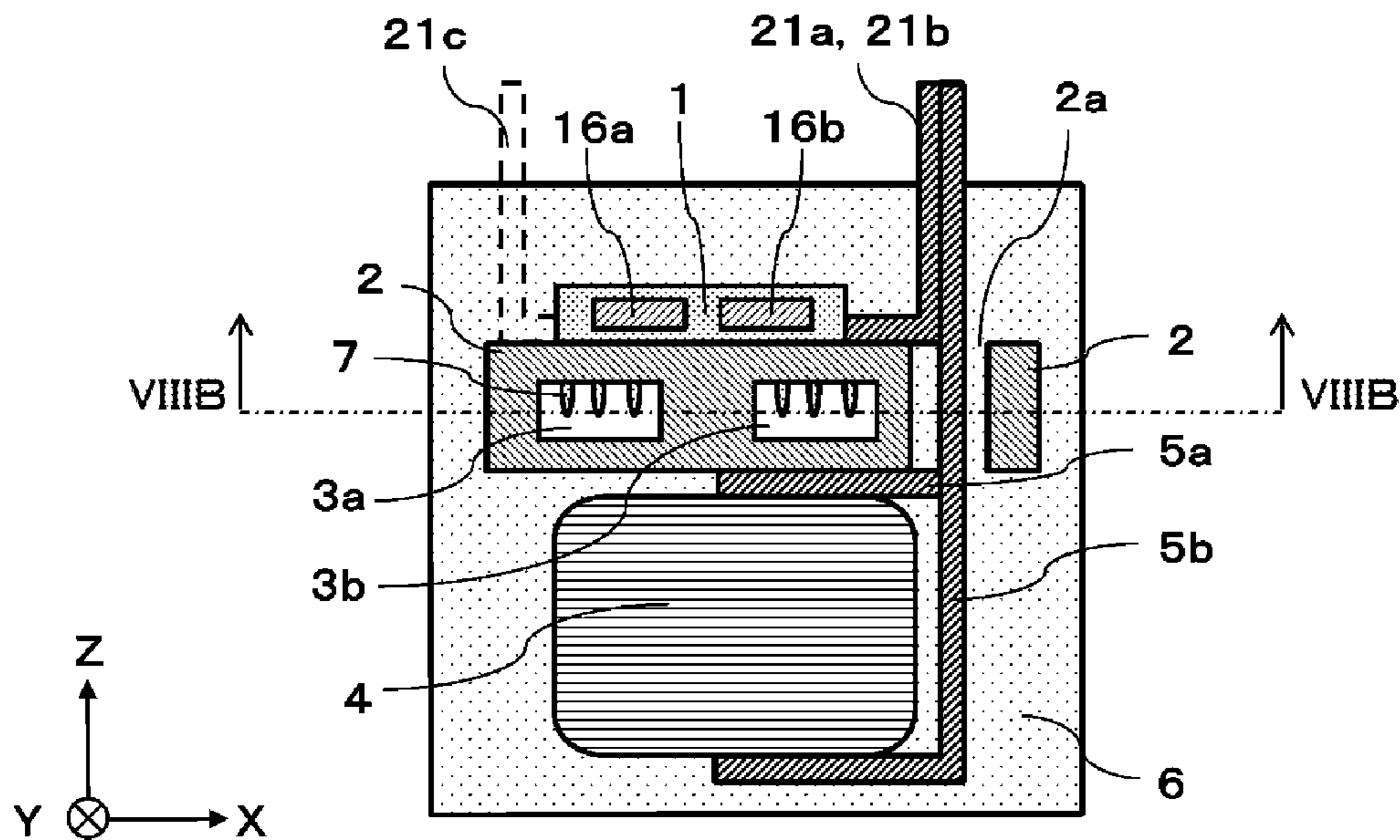


FIG. 8B

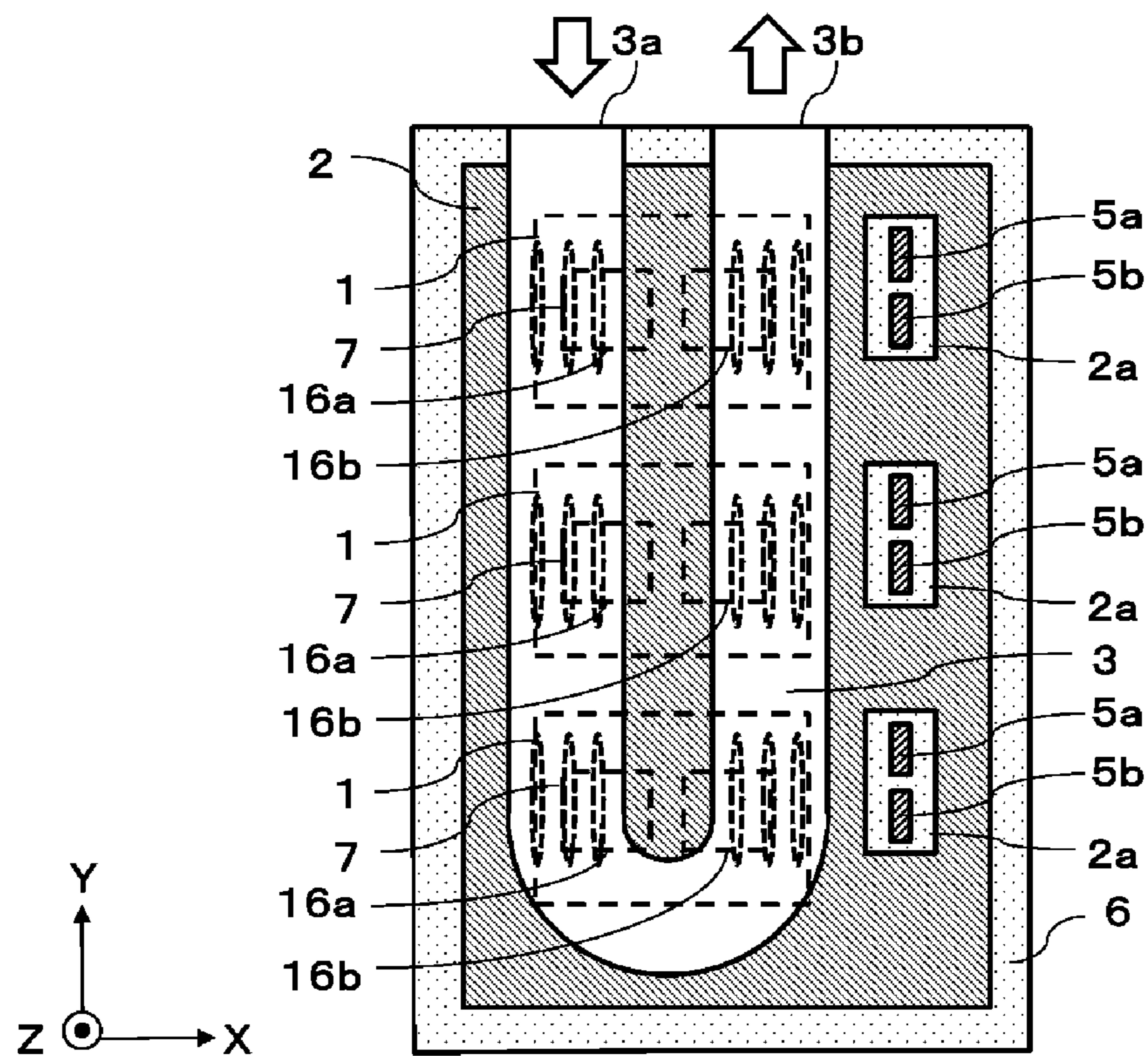


FIG. 9A

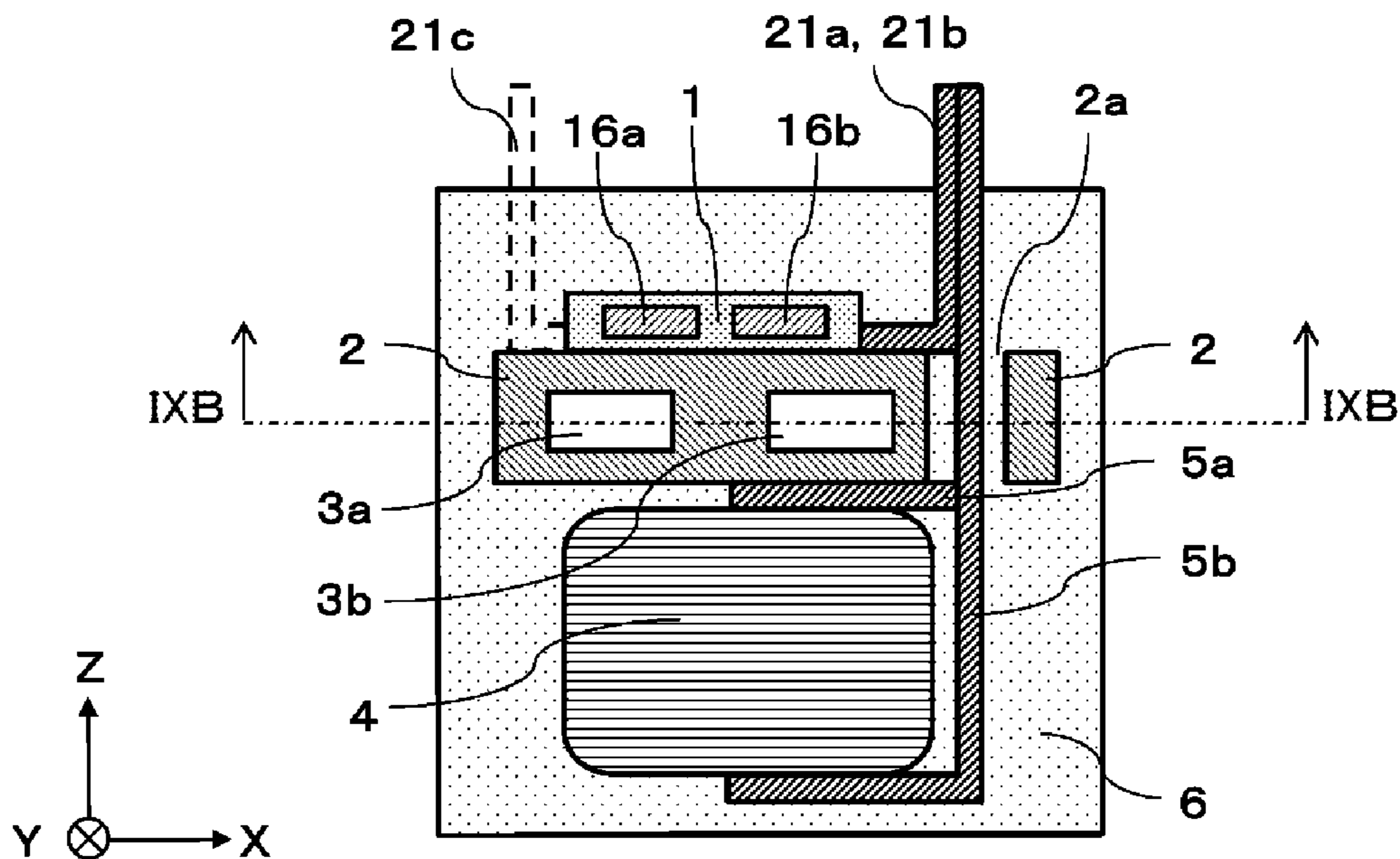


FIG. 9B

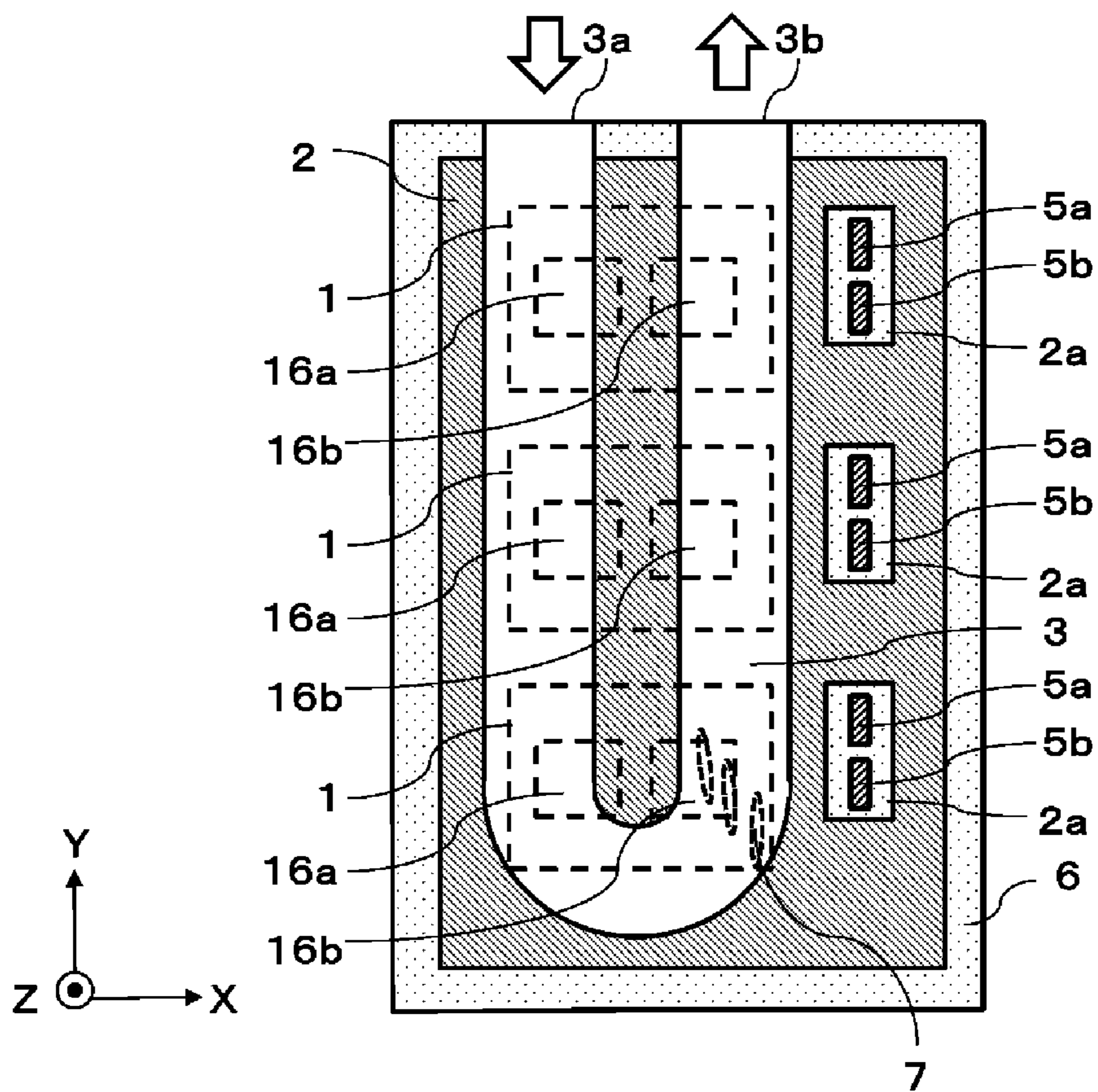


FIG. 10

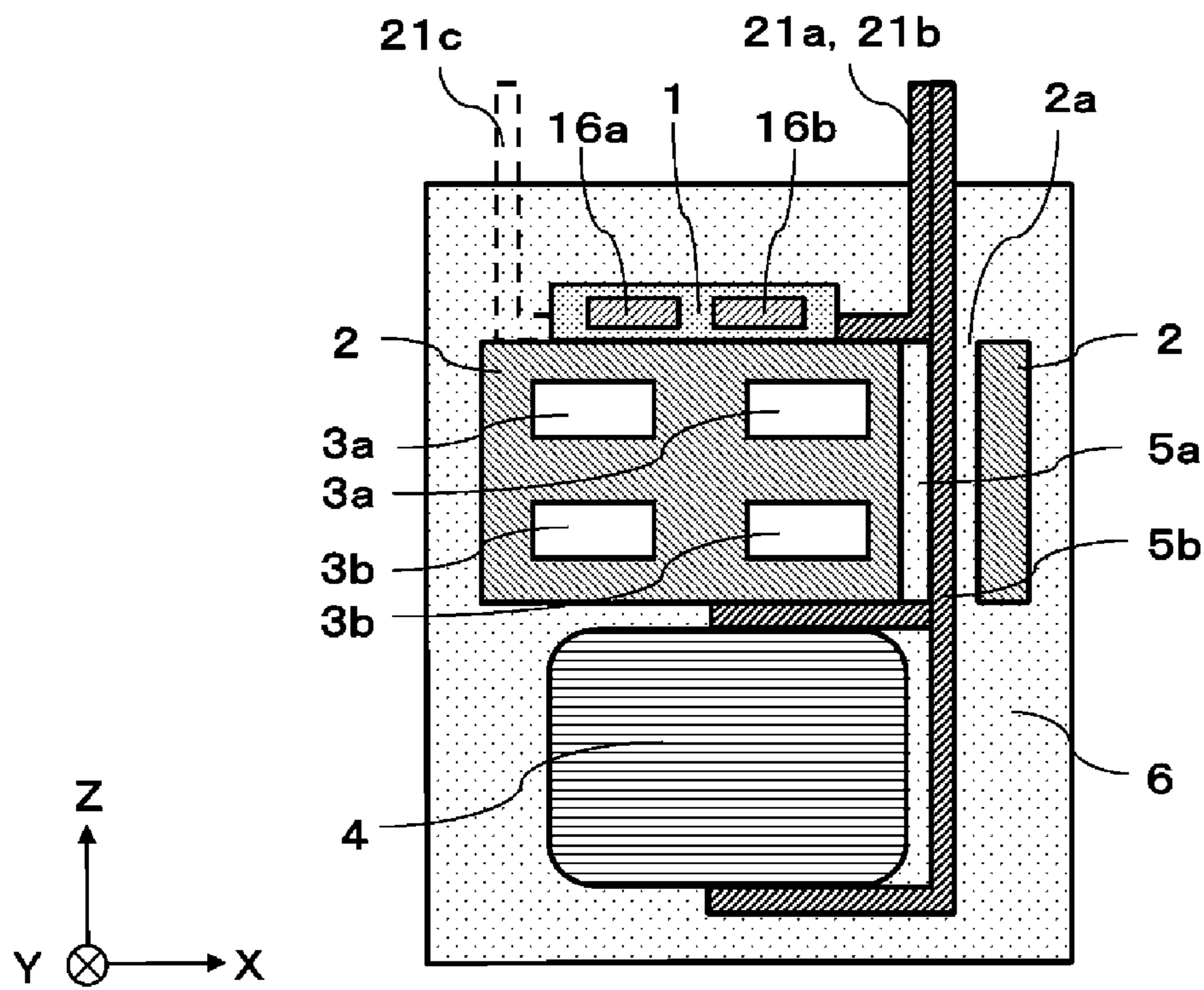


FIG. 11A

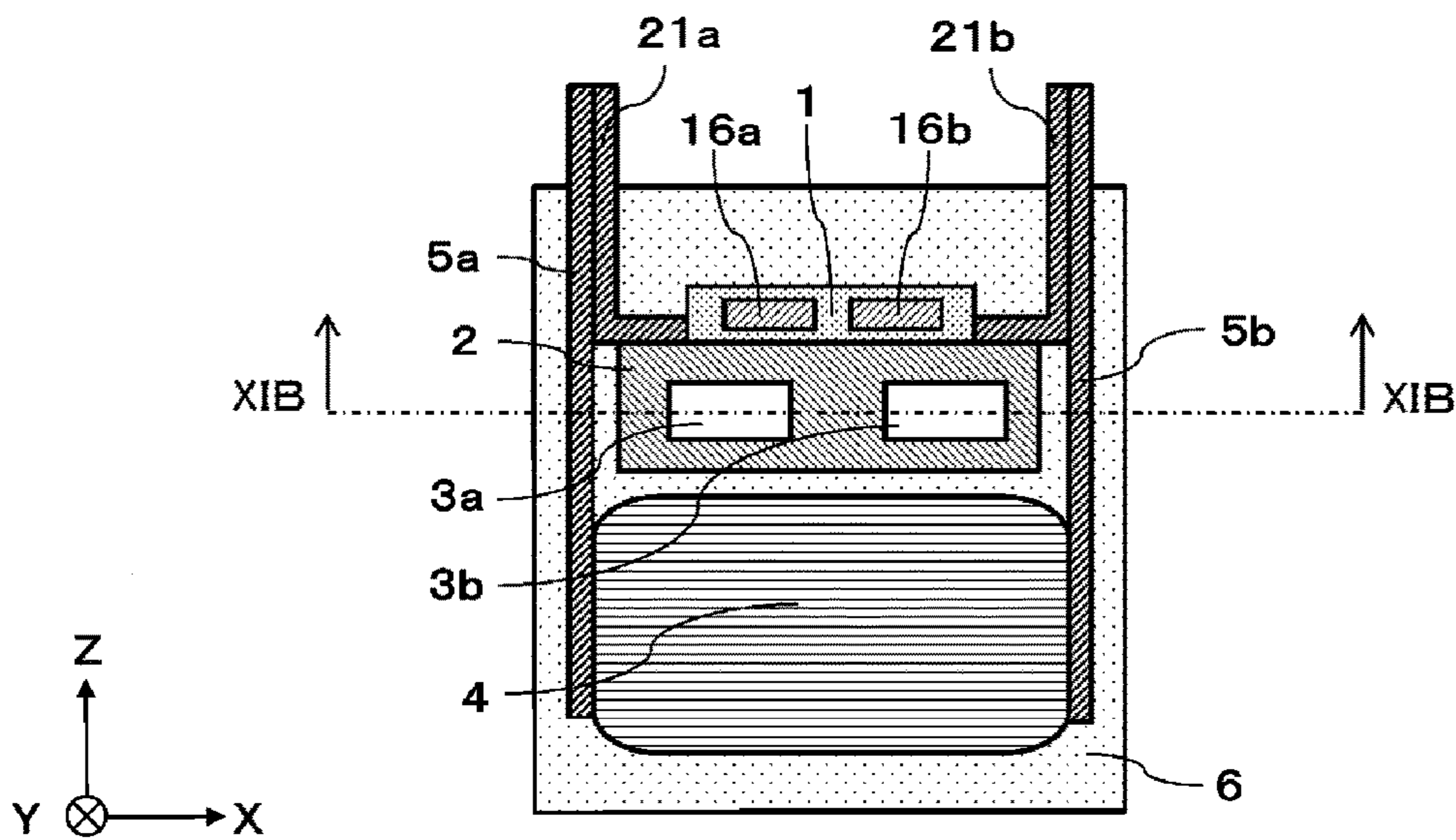


FIG. 11B

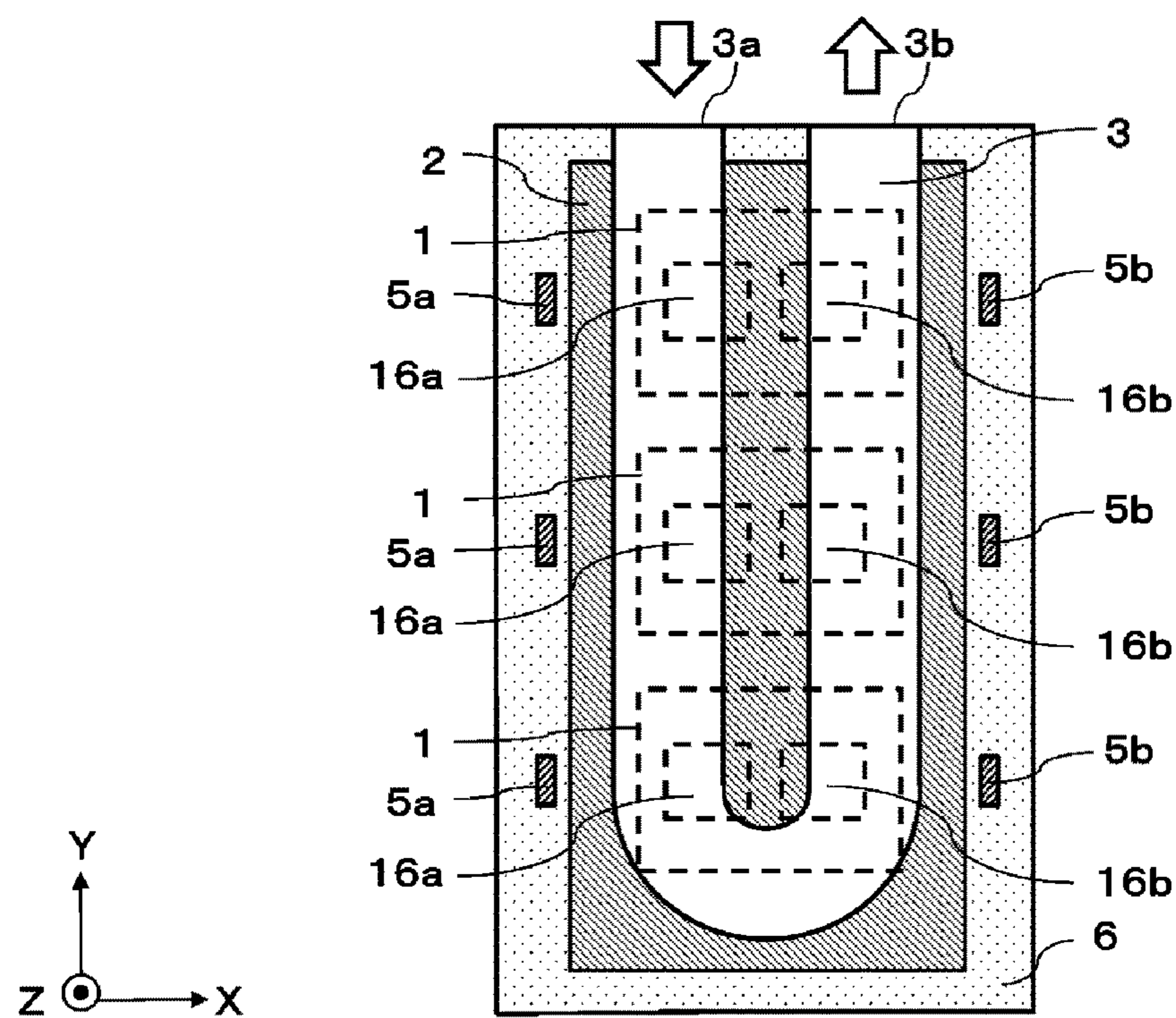


FIG. 12A

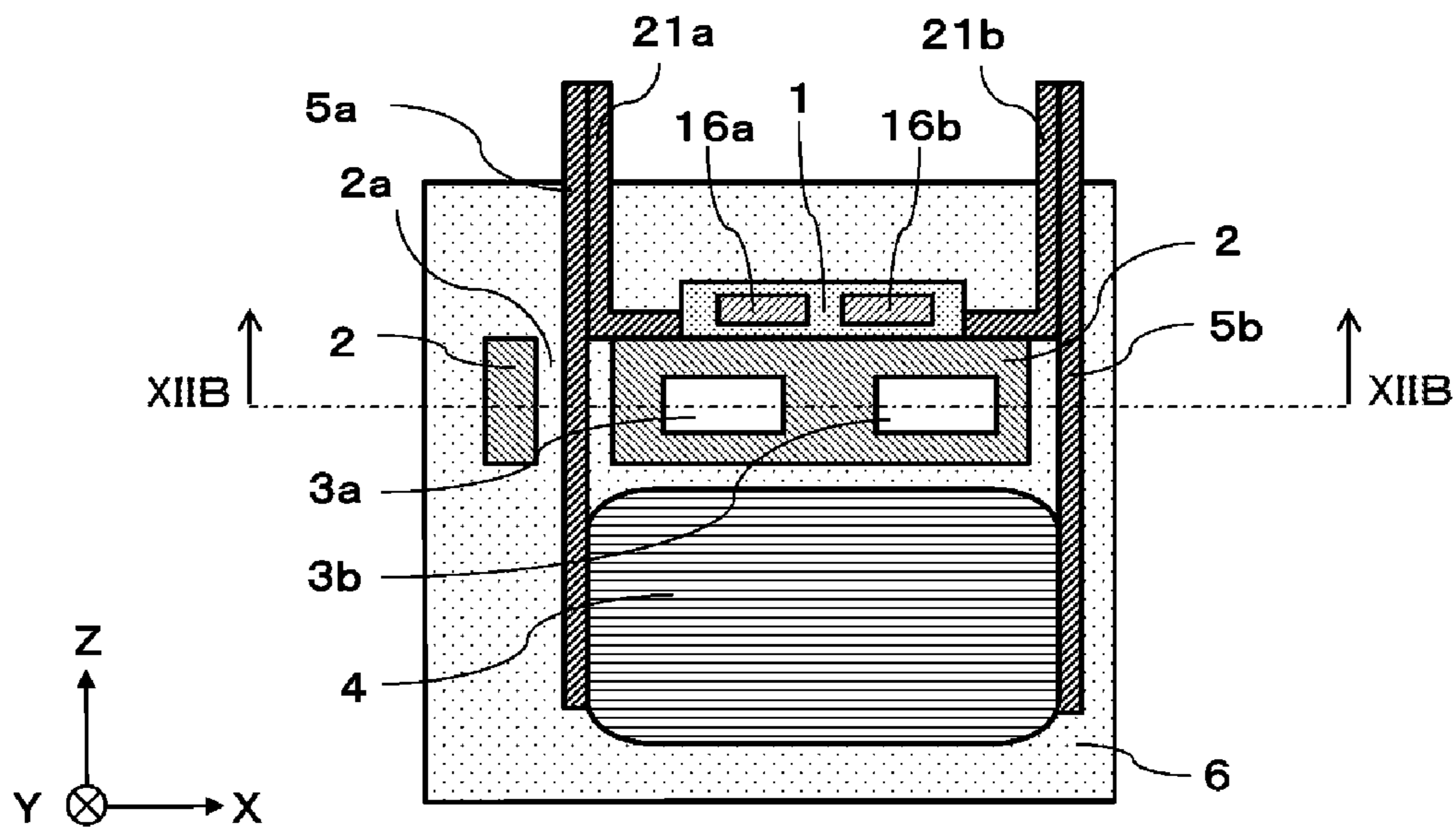


FIG. 12B

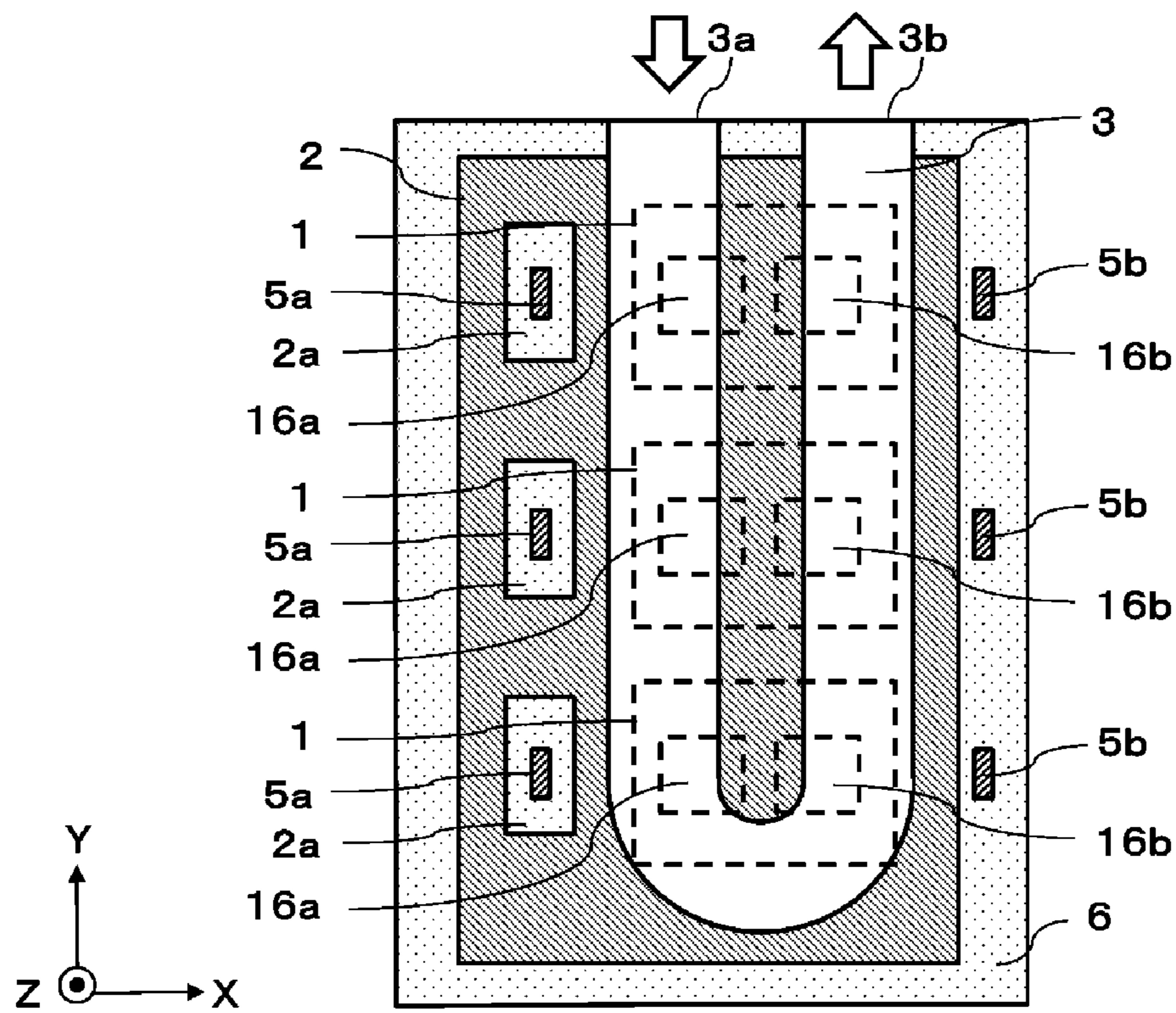


FIG. 13A

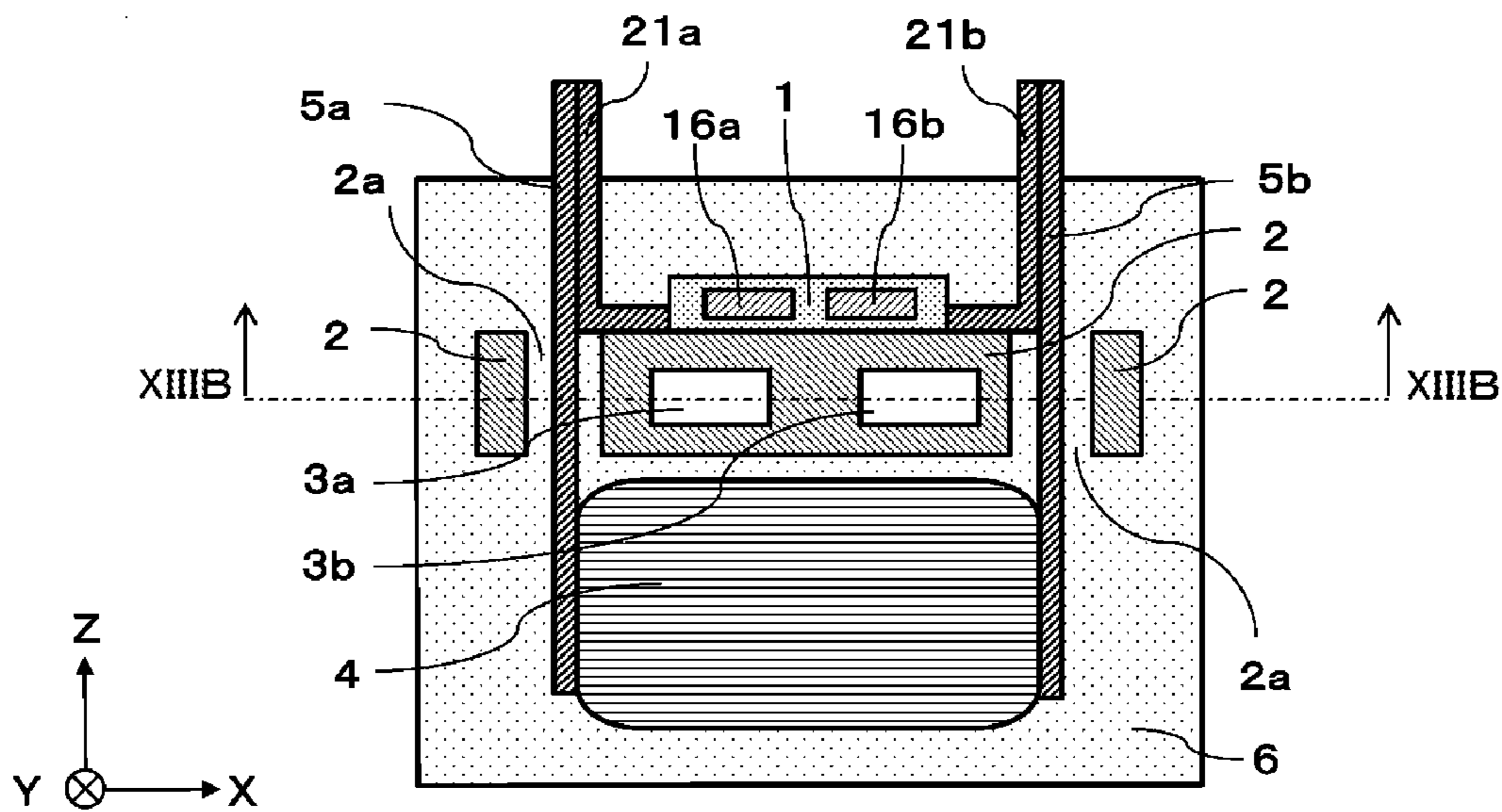


FIG. 13B

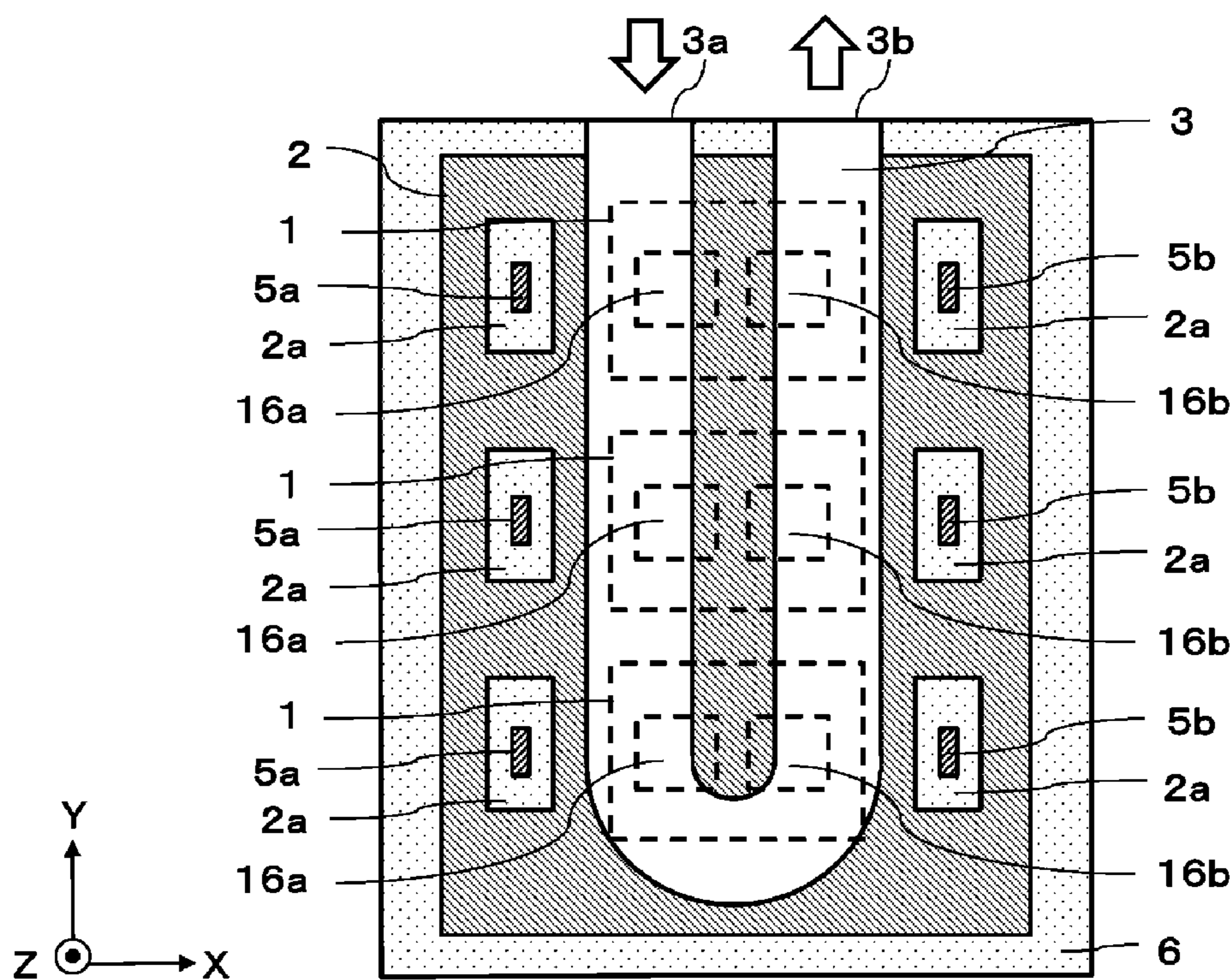


FIG. 14A

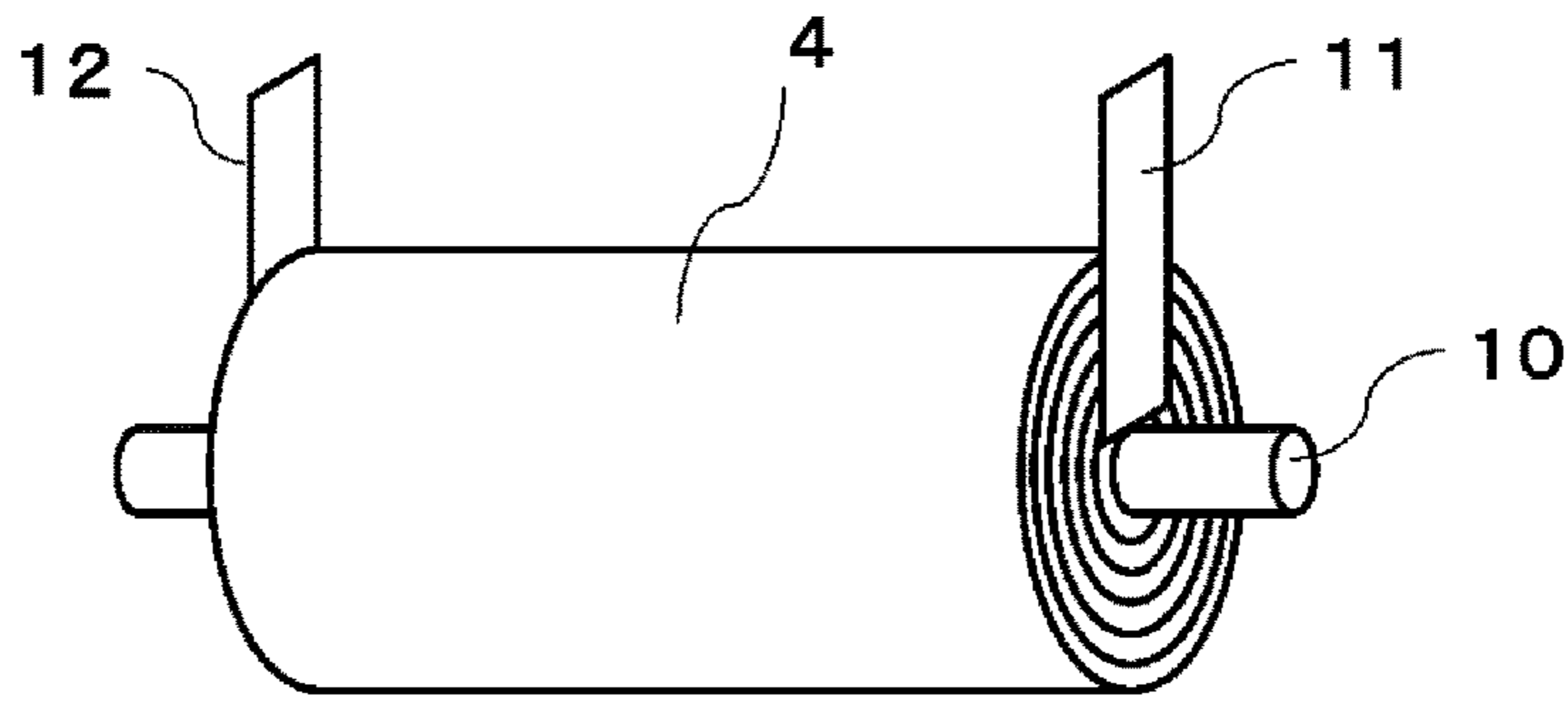


FIG. 14B

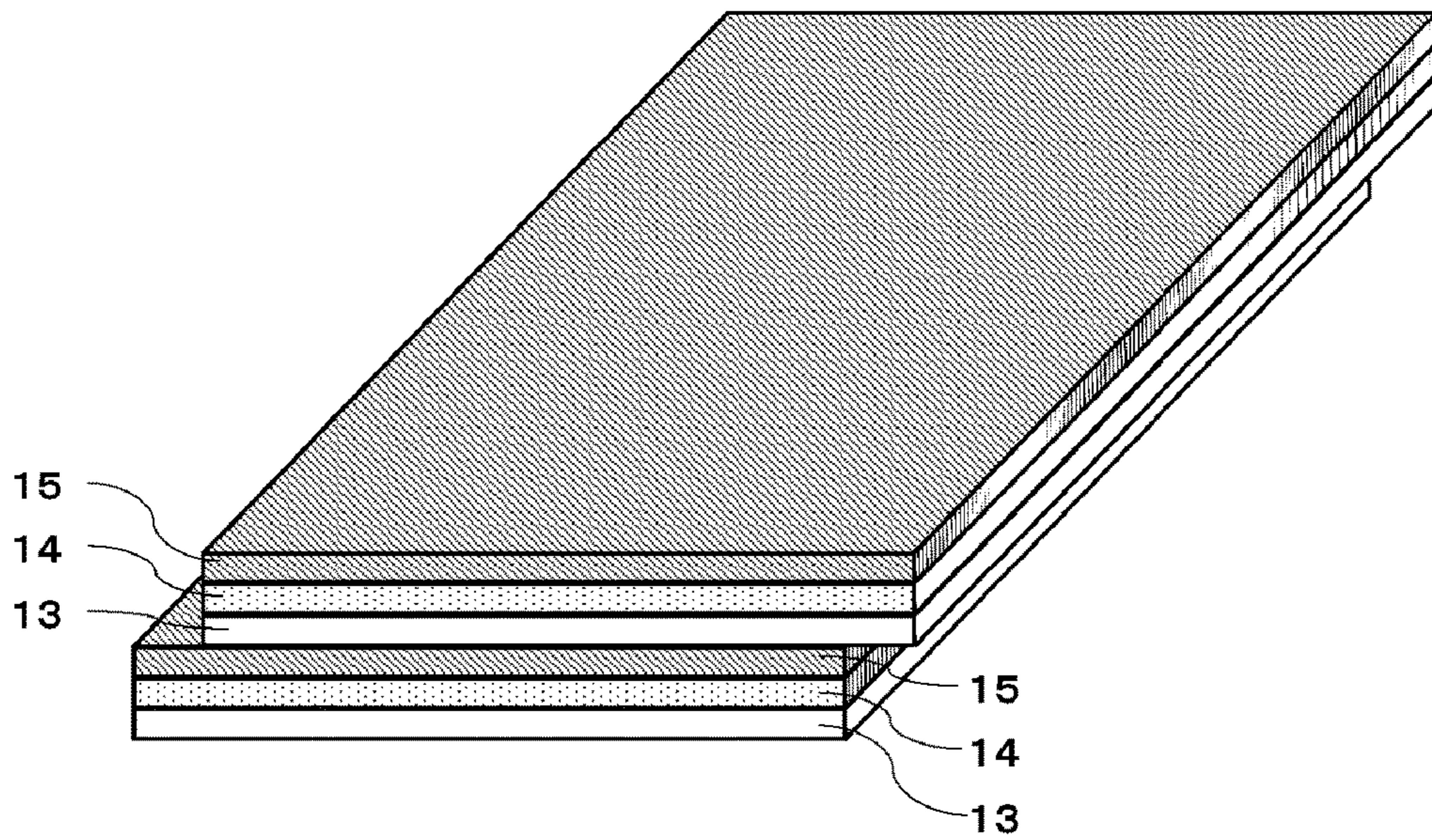


FIG. 15A

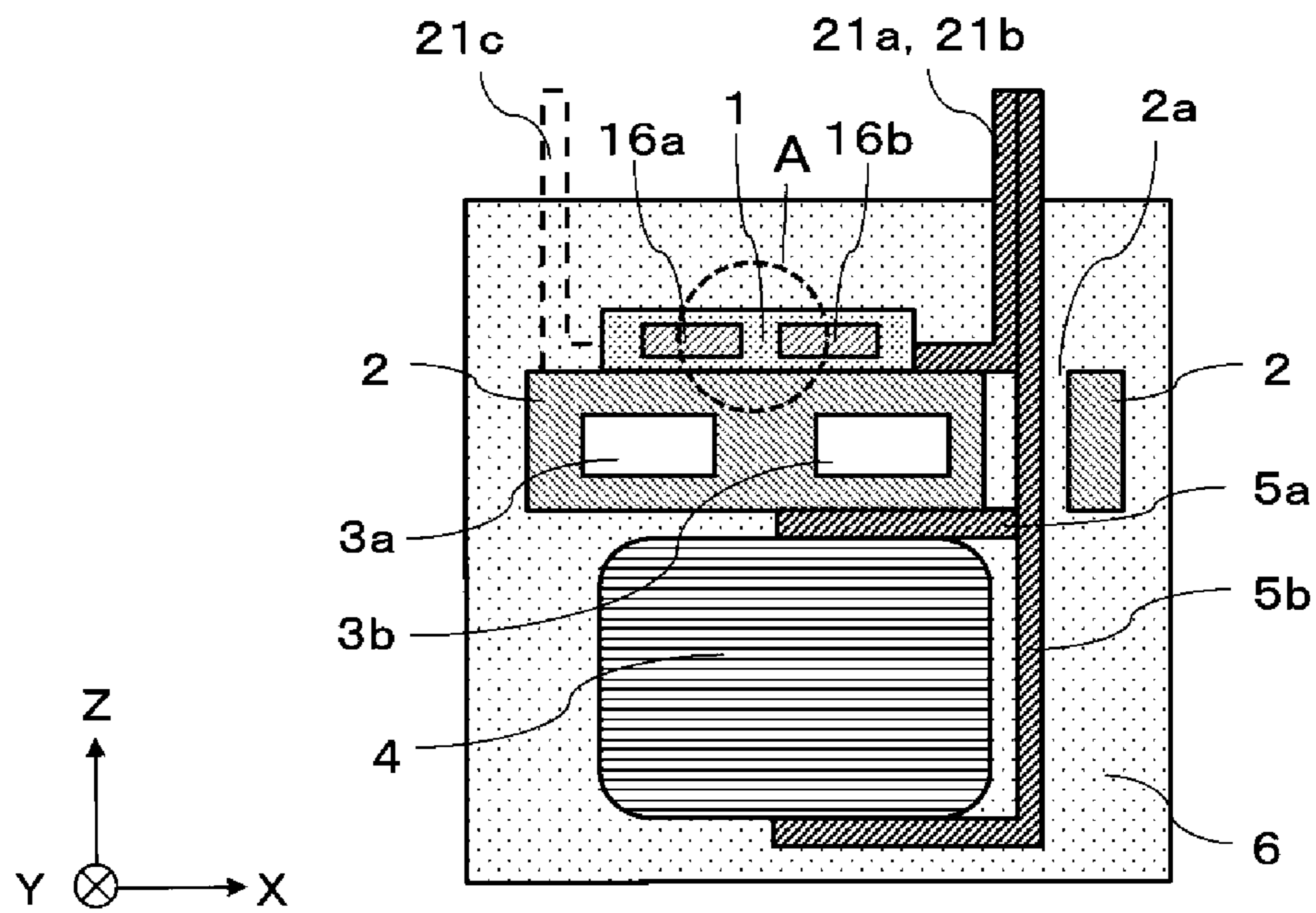


FIG. 15B

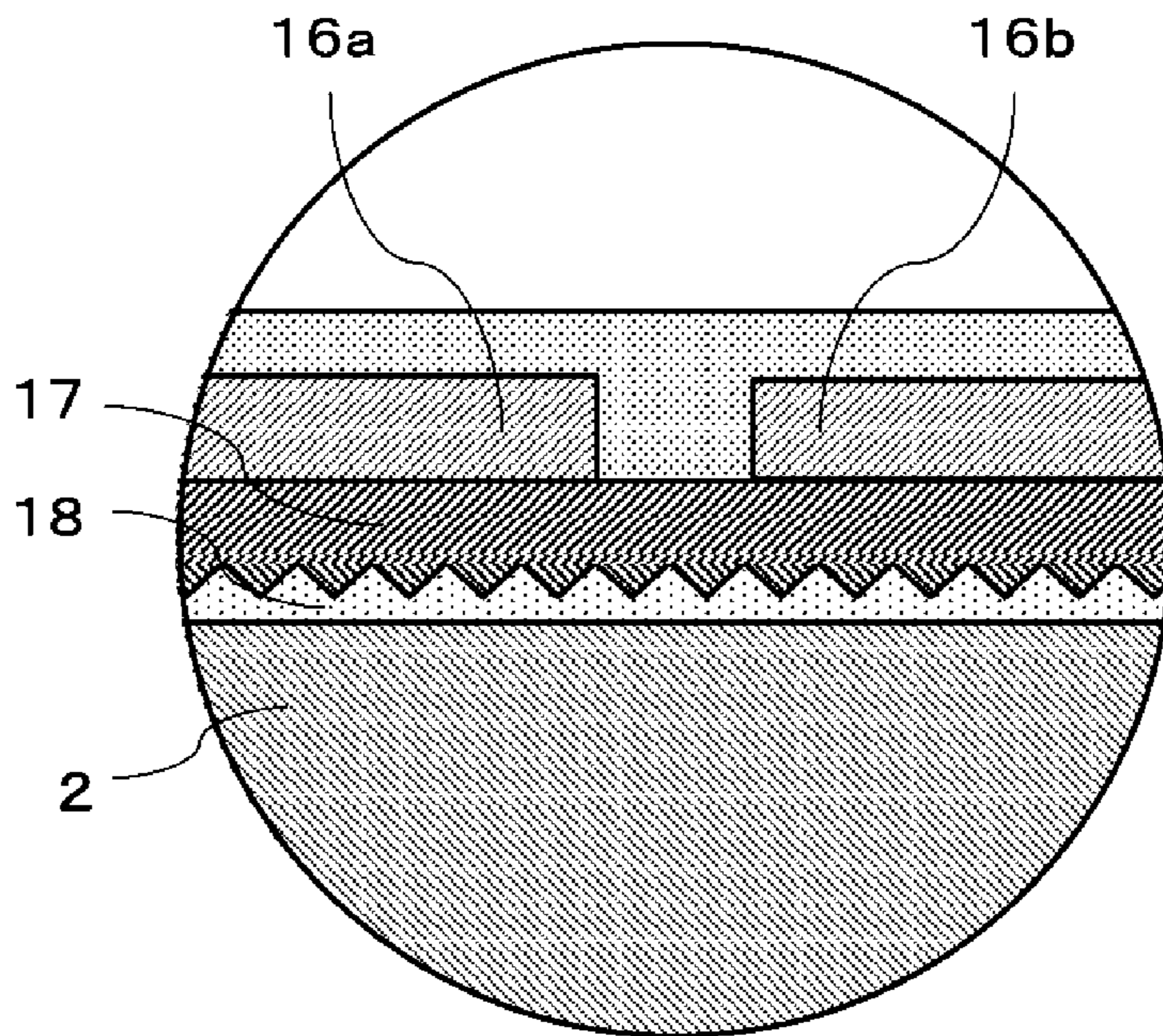


FIG. 16A

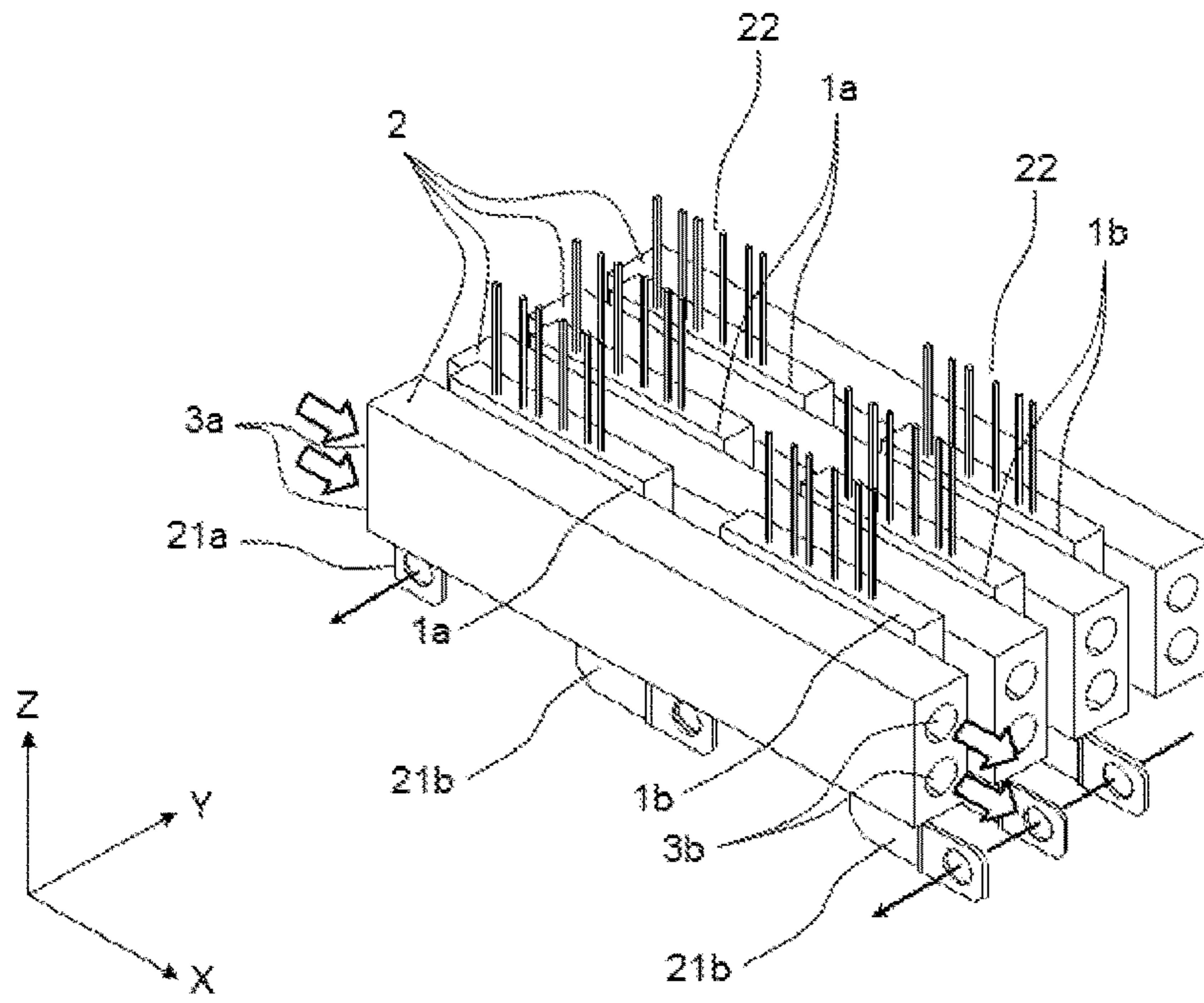


FIG. 16B

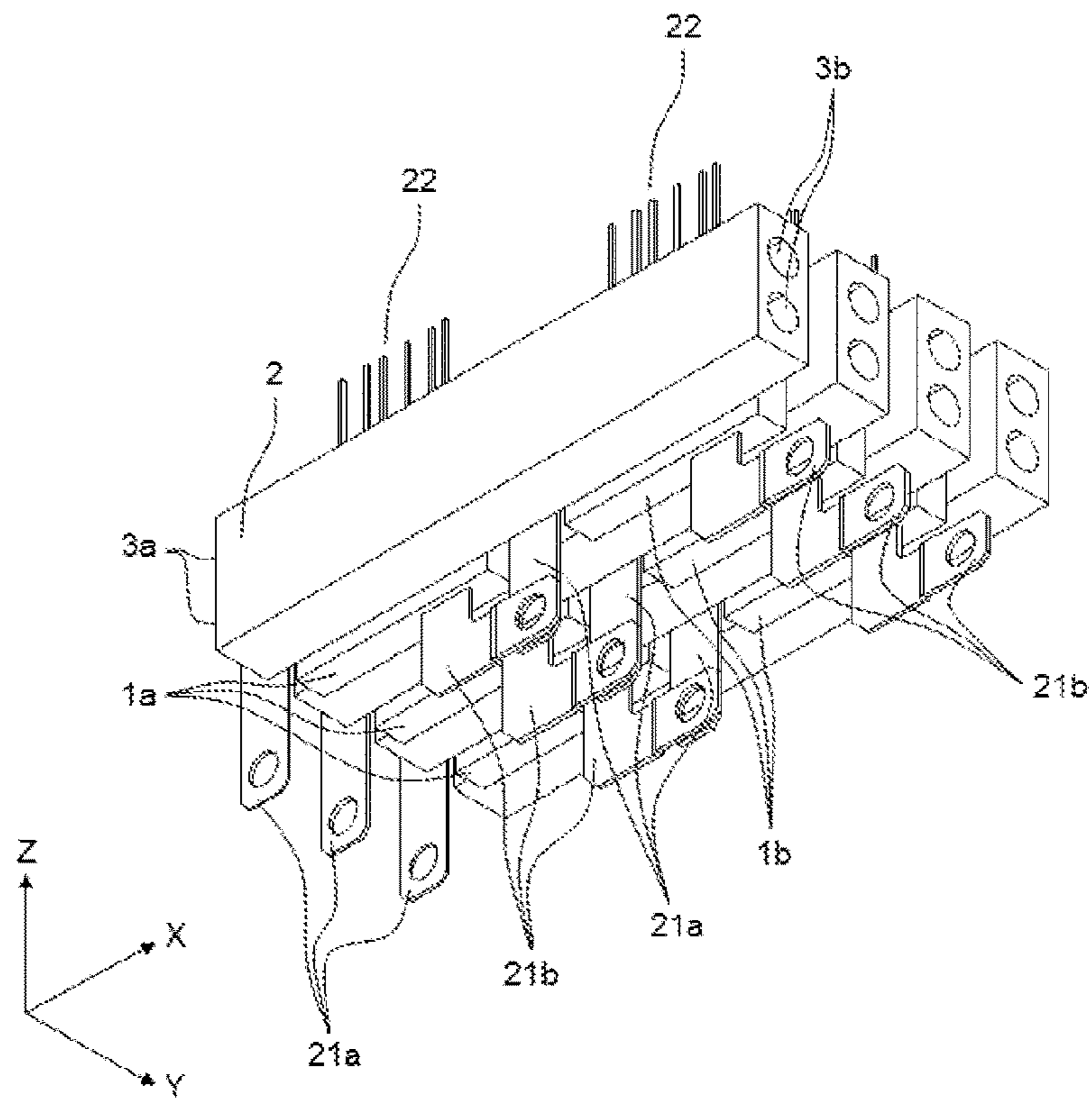


FIG. 17

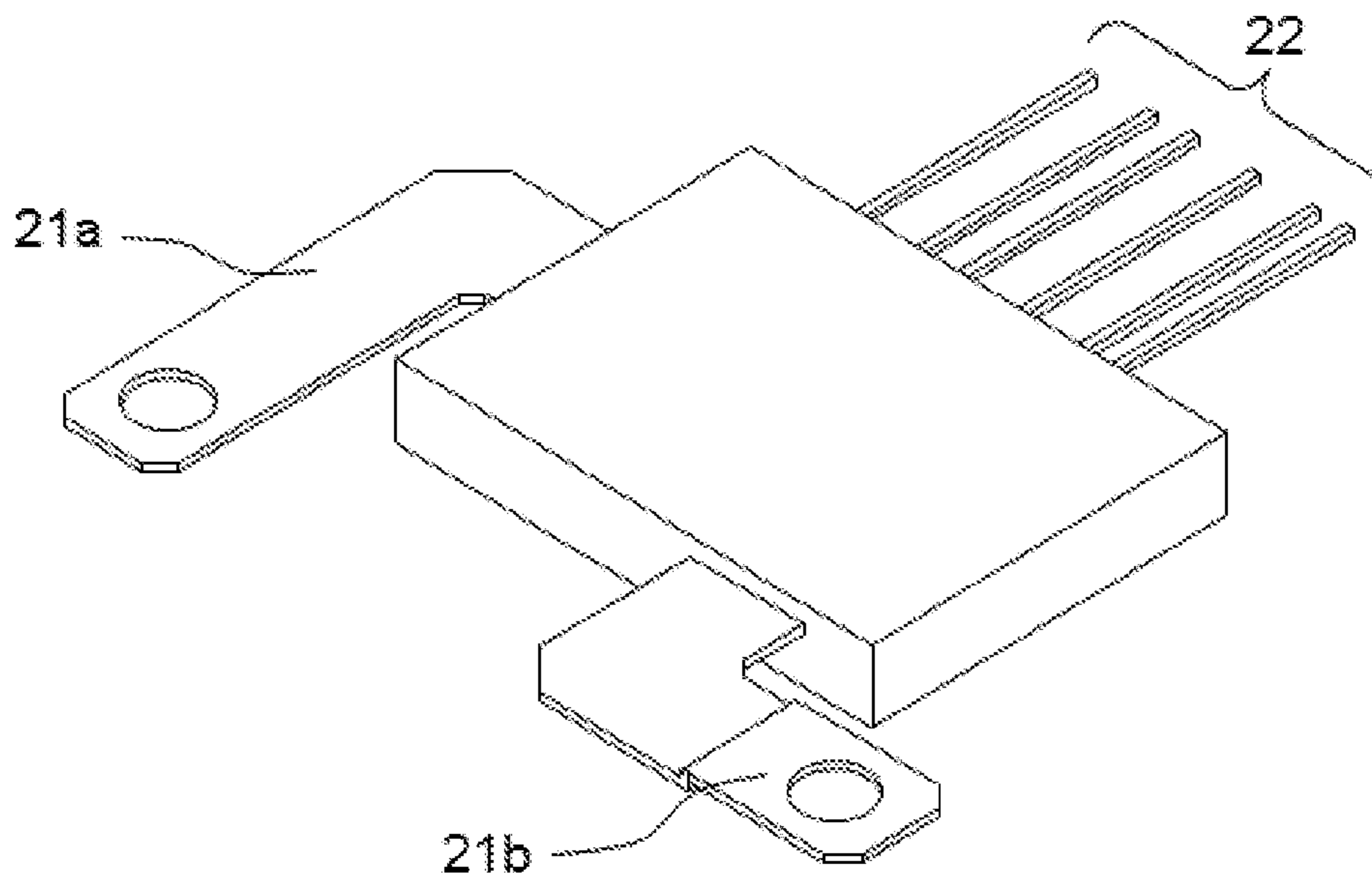


FIG. 18

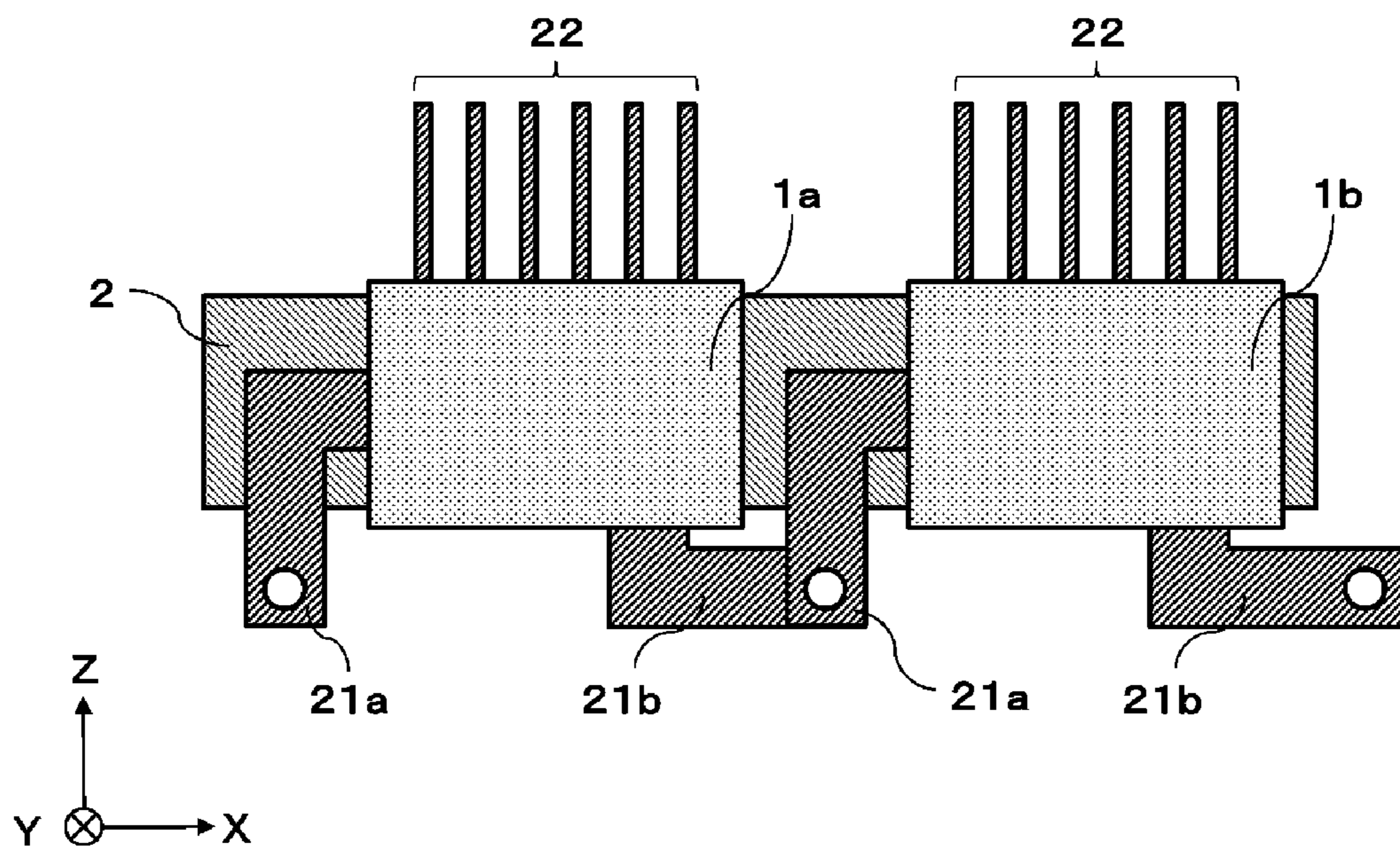


FIG. 19

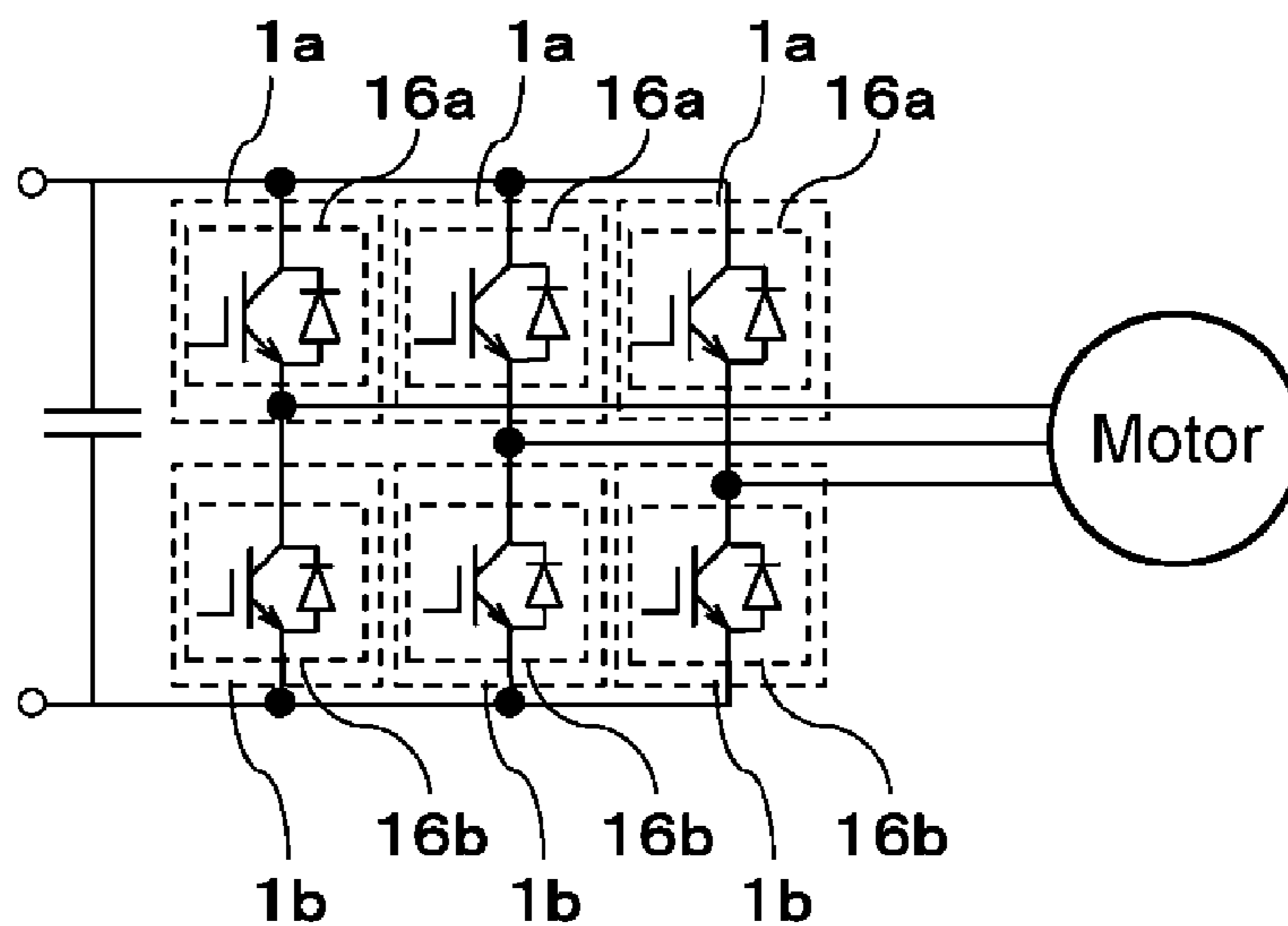


FIG. 20

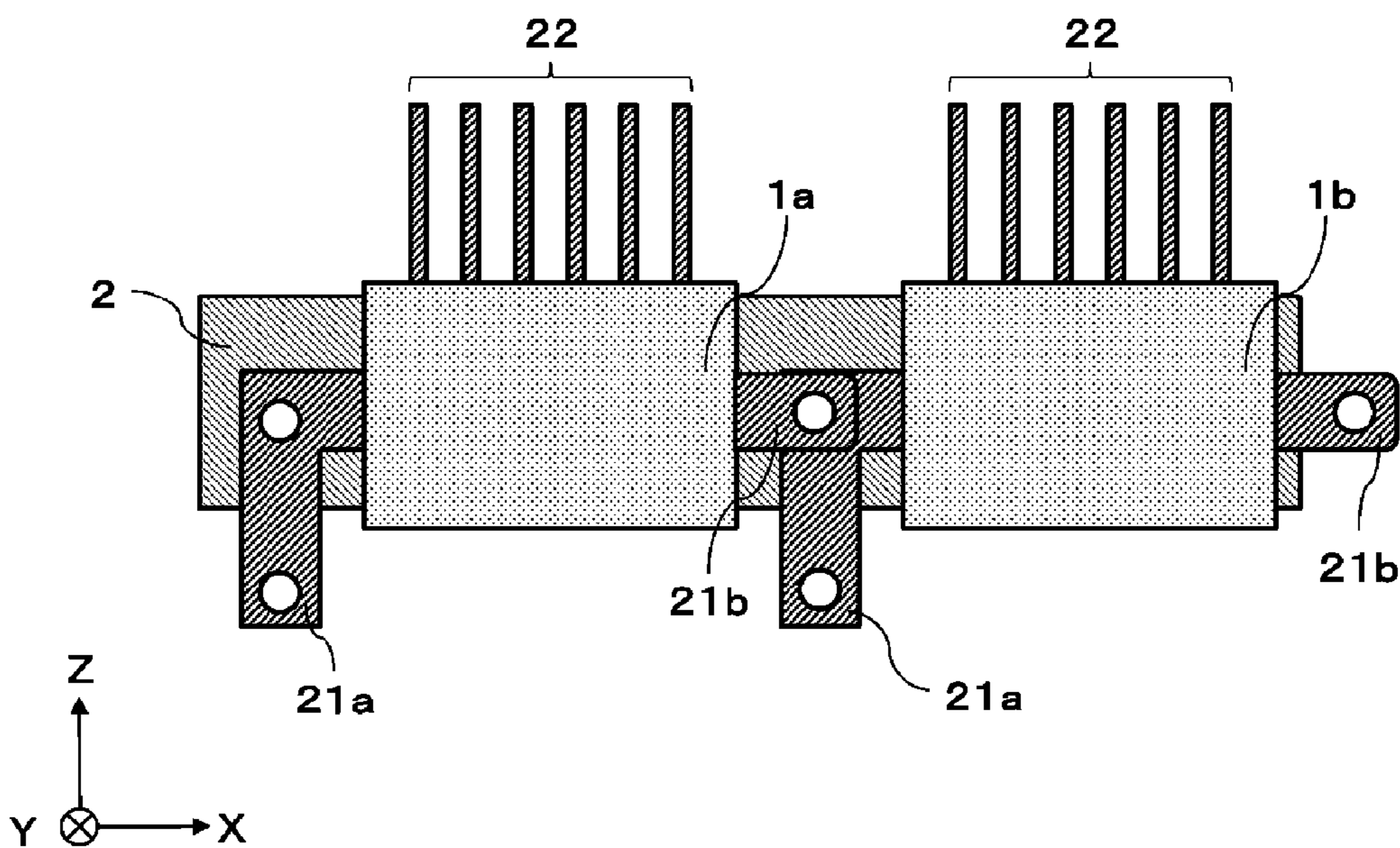


FIG. 21A

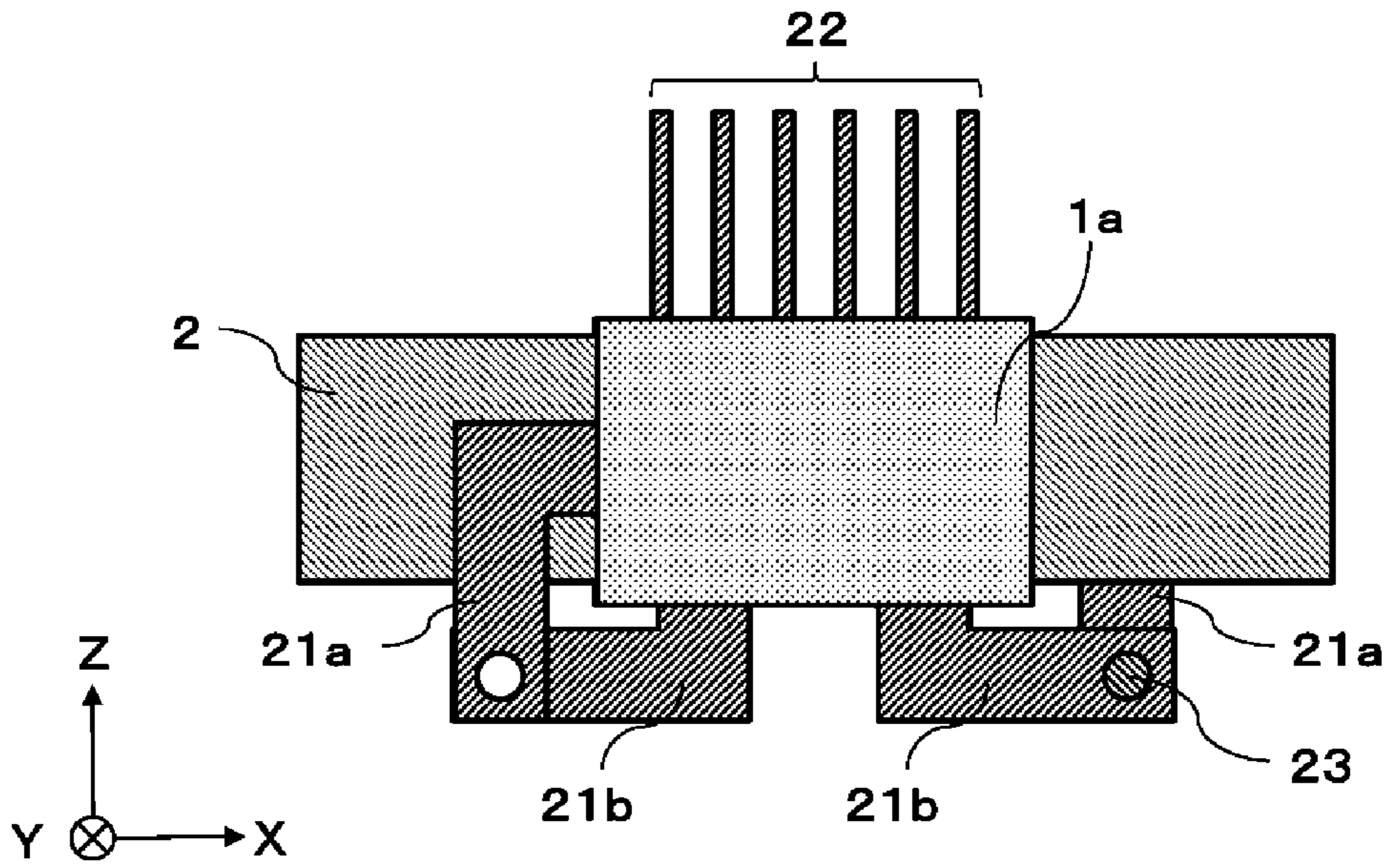


FIG. 21B

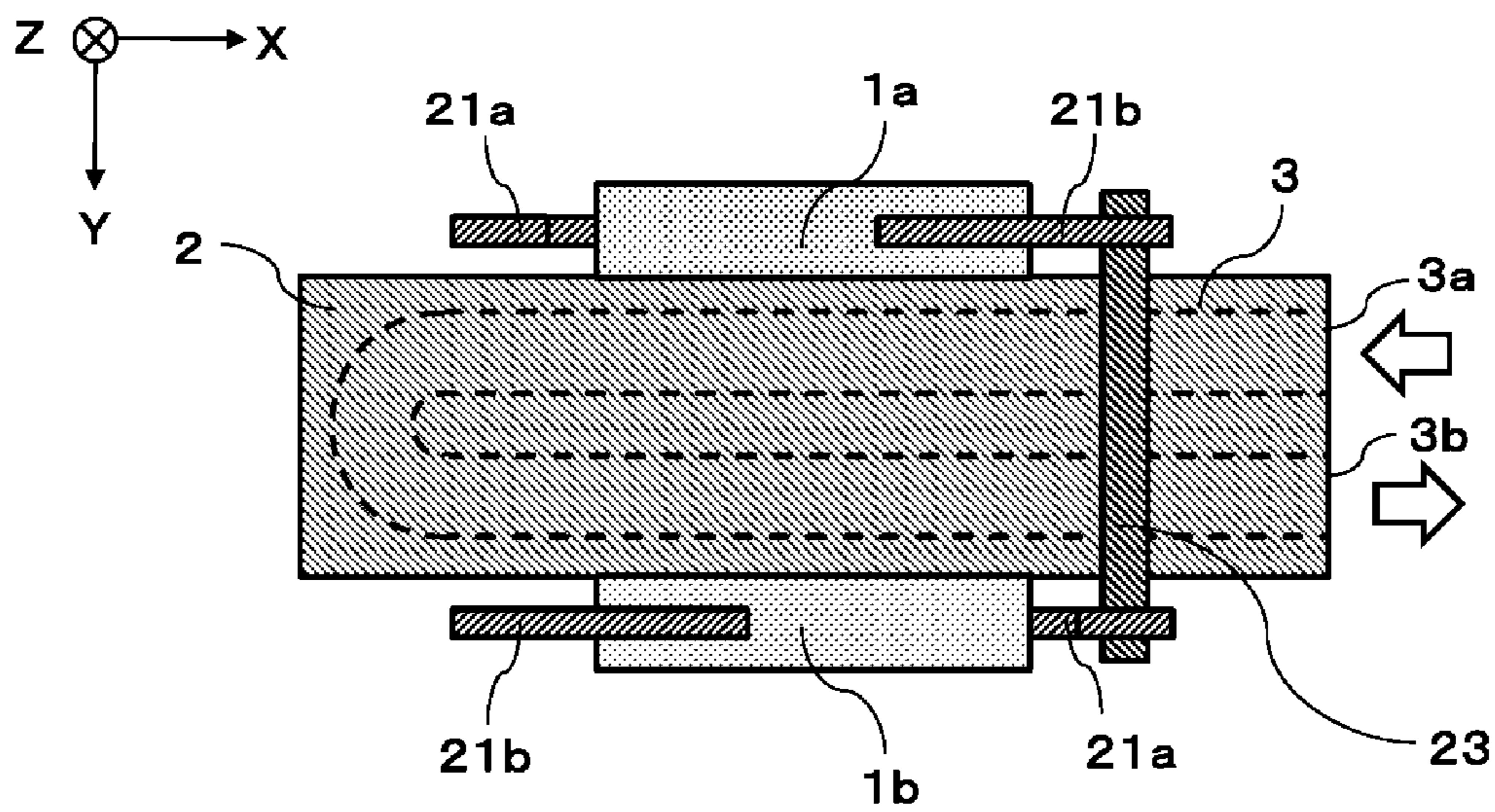


FIG. 22A

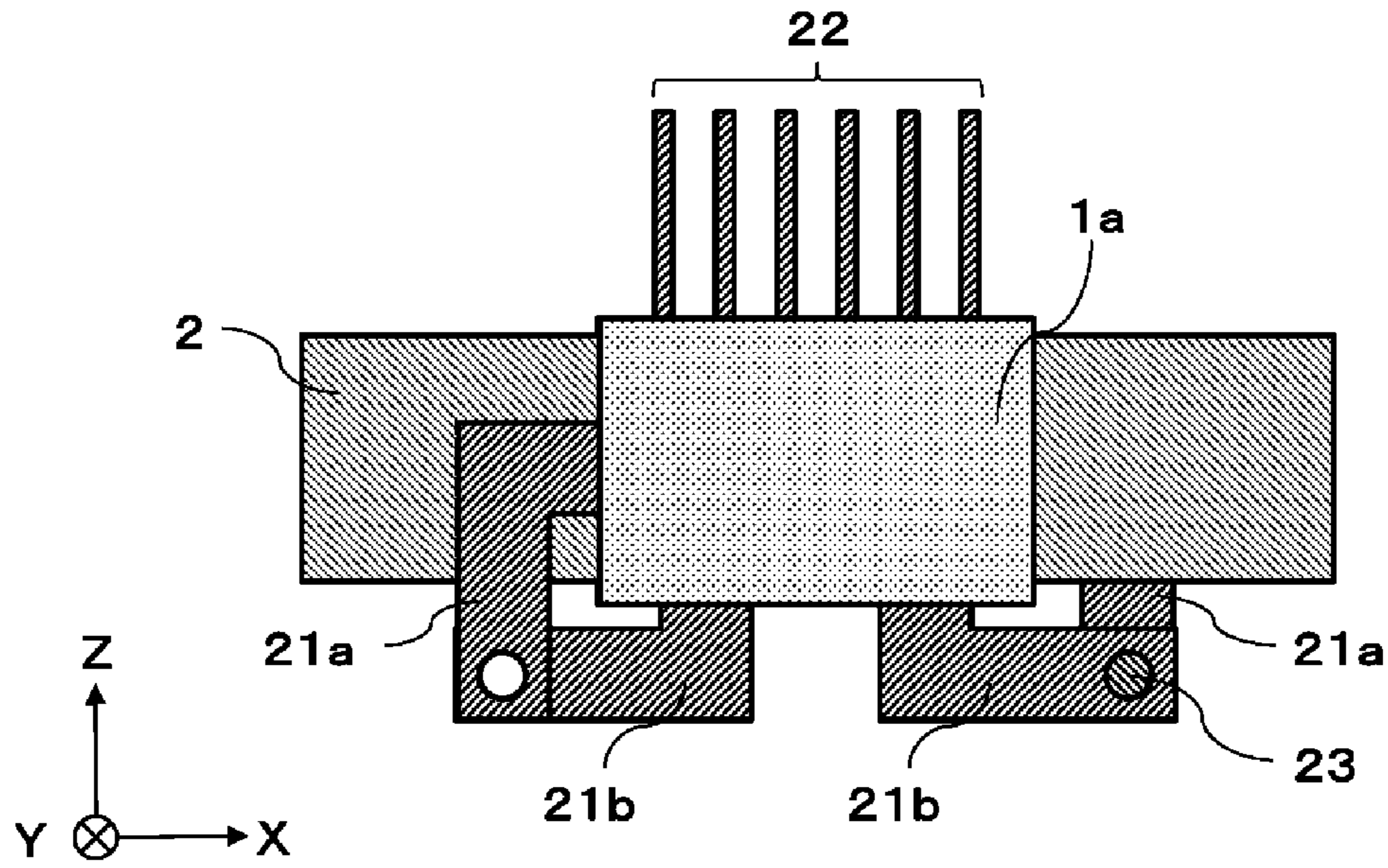


FIG. 22B

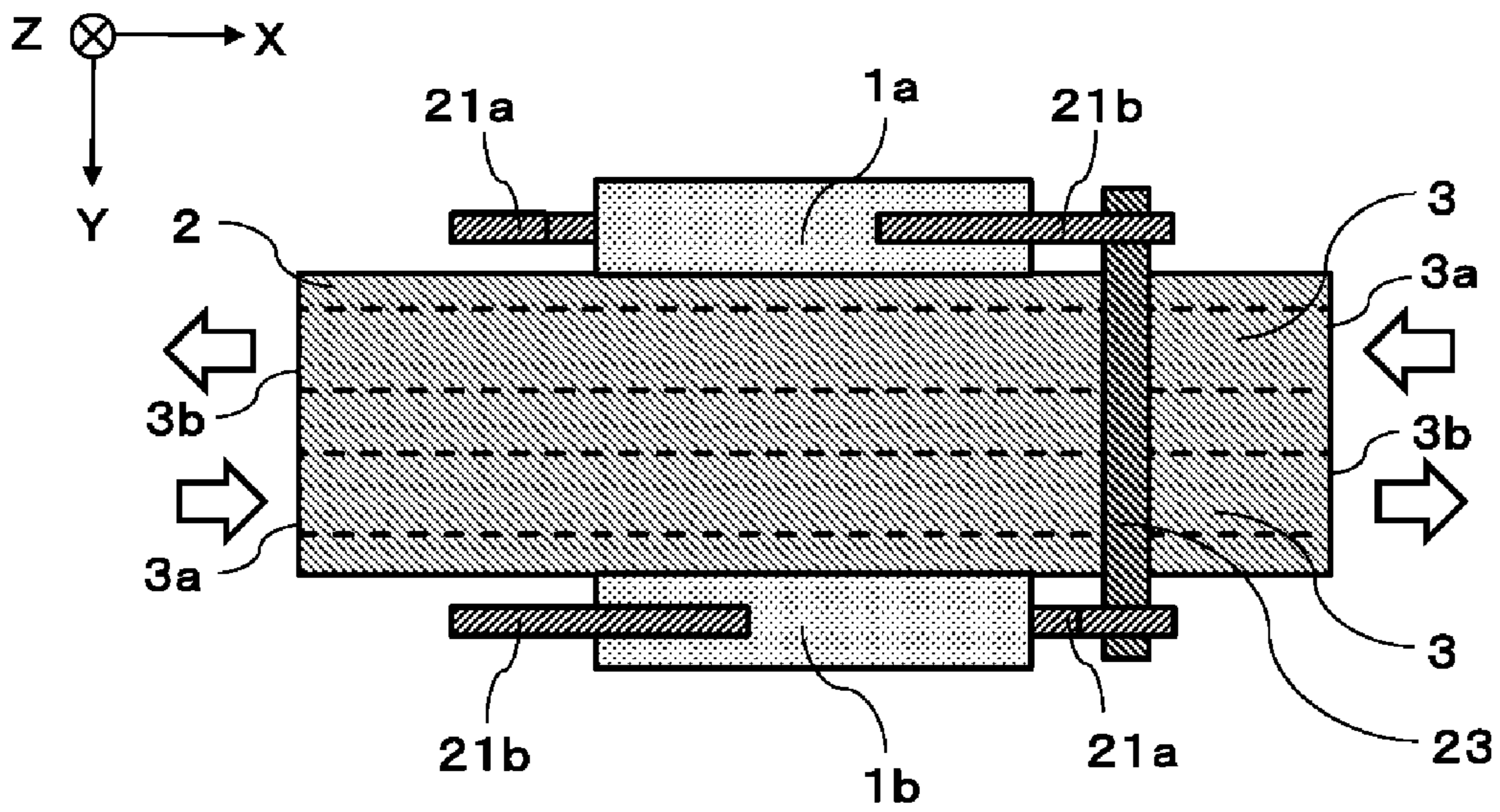
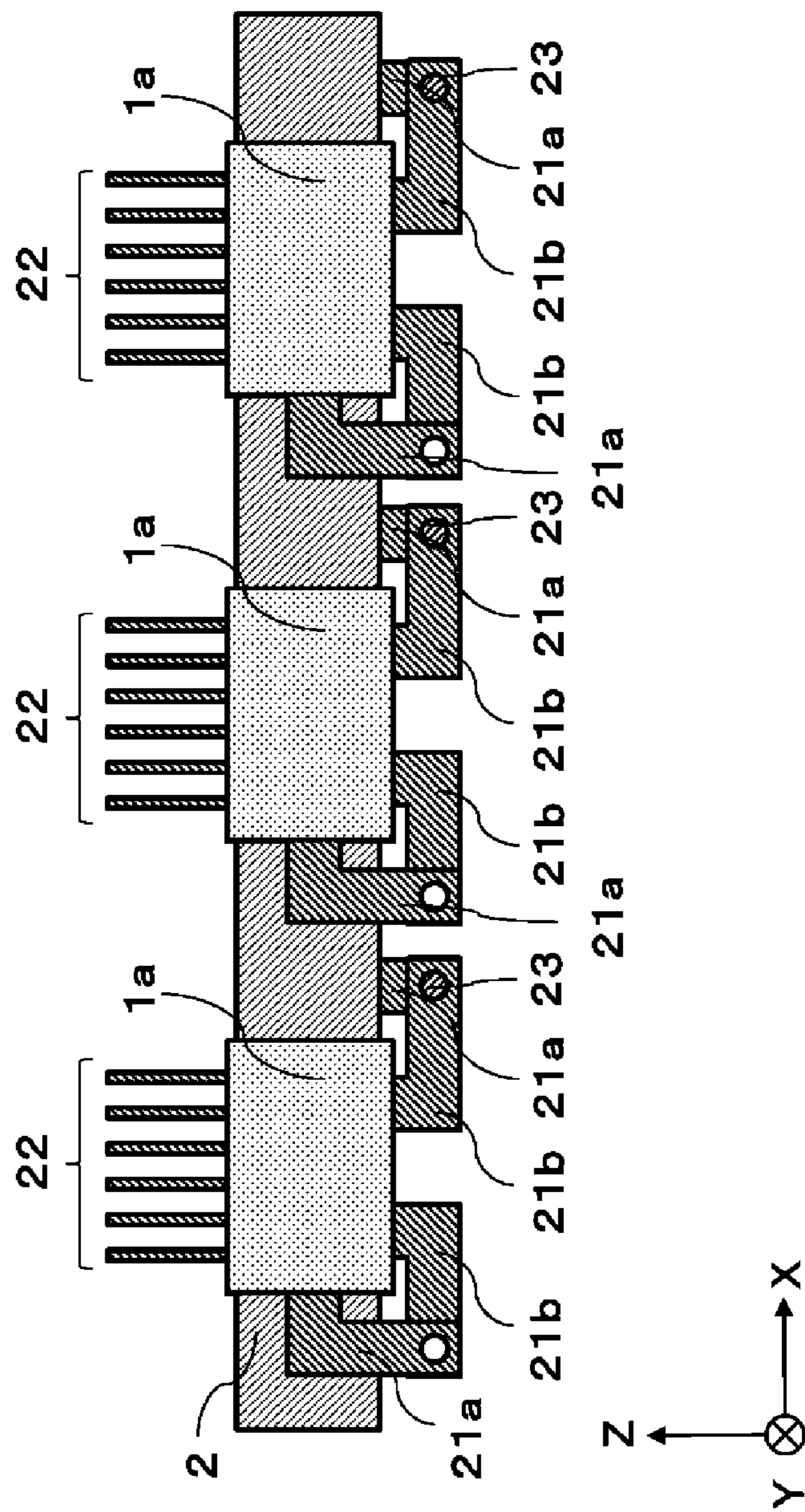


FIG. 23



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SEMICONDUCTOR DEVICE

BACKGROUND

1. Technical Field

The present disclosure relates to a semiconductor device used for power conversion in an inverter device or the like.

2. Description of the Related Art

In recent years, there is used an inverter circuit which is based on semiconductor modules in which an IGBT (Insulated Gate Bipolar Transistor) element and the like are incorporated, for driving an electric motor of an electric car, a hybrid car or the like. However, since these semiconductor modules are operated with a large current, a great amount of heat is generated. Accordingly, there may be caused a problem that a capacitor, a control circuit and the like installed in the vicinity are placed at a high temperature, resulting in malfunction.

Unexamined Japanese Patent Publication No. 2010-252461 discloses a power conversion device according to which a cooler is disposed between a semiconductor module and a capacitor, and a capacitor terminal connecting the capacitor and a semiconductor element is thermally in contact with the cooler so as to cool the capacitor terminal. Heat transfer from the semiconductor module to the capacitor is thereby suppressed, and an increase in the temperature of the capacitor is reduced.

Furthermore, Unexamined Japanese Patent Publication No. 2005-73374 discloses a power conversion device which places a semiconductor module between refrigerant tubes and cools the semiconductor module so as to reduce harmful effect and the like of heat on other devices.

SUMMARY

A first semiconductor device according to the present disclosure includes a semiconductor module including a semiconductor element, a passive element, a cooling member, a first conductive member and a second conductive member. The cooling member is disposed between the semiconductor module and the passive element. The first conductive member and the second conductive member electrically connect the semiconductor module and the passive element. Furthermore, two or more aspects of at least one of the first conductive member and the second conductive member face the cooling member.

According to the configuration, compared to a case where only one aspect of a conductive member faces a cooling member, heat dissipation from the conductive member, which is electrically connecting the semiconductor module and the passive element, to the cooling member is promoted. And heat transferred from the semiconductor module to the passive element through the conductive member may be suppressed. Accordingly, an increase in the temperature of the passive element due to heat from the semiconductor module may be suppressed.

Furthermore, a second semiconductor device according to the present disclosure includes a semiconductor module including a semiconductor element, a passive element, a cooling member, a first conductive member and a second conductive member. The cooling member is disposed between the semiconductor module and the passive element. The first conductive member and the second conductive member electrically connect the semiconductor module and the passive element. The cooling member and the semiconductor module are disposed between the first conductive member and the second conductive member.

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According to the configuration, the conductive members connecting the semiconductor module and the passive element are cooled by the cooling member disposed between the two conductive members. Therefore, an increase in the temperature of the passive element due to the heat from the semiconductor module is suppressed. Also, since the two conductive members connect the semiconductor module and the passive element from both sides of the cooling member, the conductive members do not need to make a detour through the cooling member and the passive element. Accordingly, the lengths of the conductive members may be made short. An increase in inductance may thereby be suppressed.

Moreover, a third semiconductor device according to the present disclosure includes a first semiconductor module including a first semiconductor element, a second semiconductor module including a second semiconductor element, and a cooling member where the first semiconductor module and the second semiconductor module are installed. The first semiconductor module and the second semiconductor module are installed on a side surface of the cooling member. The first semiconductor module includes a first power terminal and a second power terminal that are electrically connected to the first semiconductor element and that protrude from the first semiconductor module. And the second semiconductor module includes a third power terminal and a fourth power terminal that are electrically connected to the second semiconductor element and that protrude from the second semiconductor module. The second power terminal of the first semiconductor module is connected to the third power terminal of the second semiconductor module. The third power terminal of the second semiconductor module protrudes from the second semiconductor module, at a position facing the side surface of the cooling member.

According to the configuration, cooling may be performed also by the power terminals protruding from the semiconductor module, at a position facing the side surface of the cooling member. Therefore, a plurality of semiconductor modules connected to each other may be sufficiently cooled. In addition, since the semiconductor modules may be electrically connected over a short distance, an increase in inductance may be suppressed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a schematic perspective view of a semiconductor device according to a first exemplary embodiment;

FIG. 1B is a schematic side view of the semiconductor device according to the first exemplary embodiment;

FIG. 1C is a schematic perspective view of a first bus bar of the semiconductor device according to the first exemplary embodiment;

FIG. 1D is a schematic perspective view of a second bus bar of the semiconductor device according to the first exemplary embodiment;

FIG. 2A is a schematic cross-sectional view of the semiconductor device according to the first exemplary embodiment, along a line IIA-IIA in FIG. 1B;

FIG. 2B is a schematic cross-sectional view of the semiconductor device according to the first exemplary embodiment, along a line IIB-IIB in FIG. 2A;

FIG. 3 is a diagram showing a circuit of the semiconductor device according to the first exemplary embodiment;

FIG. 4 is a schematic cross-sectional view of the semiconductor device according to the first exemplary embodiment where arrangement of bus bars is changed, the sche-

matic cross-sectional view showing a position corresponding to the line IIB-IIB in FIG. 2A;

FIG. 5A is a schematic cross-sectional view of a semiconductor device according to a second exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 5B is a schematic cross-sectional view of the semiconductor device according to the second exemplary embodiment, along a line VB-VB in FIG. 5A;

FIG. 6A is a schematic cross-sectional view of a semiconductor device according to a third exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 6B is a schematic cross-sectional view of the semiconductor device according to the third exemplary embodiment, along a line VIB-VIB in FIG. 6A;

FIG. 7A is a schematic cross-sectional view of a semiconductor device according to a fourth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 7B is a schematic cross-sectional view of the semiconductor device according to the fourth exemplary embodiment, along a line VIIB-VIIB in FIG. 7A;

FIG. 8A is a schematic cross-sectional view of a semiconductor device according to a fifth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 8B is a schematic cross-sectional view of the semiconductor device according to the fifth exemplary embodiment, along a line VIIIB-VIIIB in FIG. 8A;

FIG. 9A is a schematic cross-sectional view of a semiconductor device according to a sixth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 9B is a schematic cross-sectional view of the semiconductor device according to the sixth exemplary embodiment, along a line IXB-IXB in FIG. 9A;

FIG. 10 is a schematic cross-sectional view of a semiconductor device according to a seventh exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 11A is a schematic cross-sectional view of a semiconductor device according to an eighth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 11B is a schematic cross-sectional view of the semiconductor device according to the eighth exemplary embodiment, along a line XIIB-XIIB in FIG. 11A;

FIG. 12A is a schematic cross-sectional view of a semiconductor device according to a ninth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 12B is a schematic cross-sectional view of the semiconductor device according to the ninth exemplary embodiment, along a line XIIB-XIIB in FIG. 12A;

FIG. 13A is a schematic cross-sectional view of a semiconductor device according to a tenth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 13B is a schematic cross-sectional view of the semiconductor device according to the tenth exemplary embodiment, along a line XIIIIB-XIIIIB in FIG. 13A;

FIG. 14A is a schematic view of a capacitor according to a first variation;

FIG. 14B is an explanatory structural view of the capacitor according to the first variation;

FIG. 15A is a schematic cross-sectional view of a semiconductor device according to a second variation, at a position corresponding to the line IIA-IIA in FIG. 1B;

FIG. 15B is a schematic locally-enlarged view of semiconductor elements of the semiconductor device according to the second variation and their surroundings;

FIG. 16A is a schematic perspective view of a semiconductor device according to an eleventh exemplary embodiment, seen from above;

FIG. 16B is a schematic perspective view of the semiconductor device according to the eleventh exemplary embodiment, seen from below;

FIG. 17 is a schematic perspective view of a semiconductor module according to the eleventh exemplary embodiment;

FIG. 18 is a schematic view describing connection between semiconductor modules according to the eleventh exemplary embodiment;

FIG. 19 is a diagram showing a circuit of the semiconductor device according to the eleventh exemplary embodiment;

FIG. 20 is a schematic view describing connection between semiconductor modules according to a twelfth exemplary embodiment;

FIG. 21A is a schematic side view of a semiconductor device according to a thirteenth exemplary embodiment;

FIG. 21B is a schematic bottom view of the semiconductor device according to the thirteenth exemplary embodiment;

FIG. 22A is a schematic side view of a semiconductor device according to a fourteenth exemplary embodiment;

FIG. 22B is a schematic bottom view of the semiconductor device according to the fourteenth exemplary embodiment; and

FIG. 23 is a schematic side view of a semiconductor device according to a fifteenth exemplary embodiment.

DESCRIPTION OF EMBODIMENTS

First, problems of conventional techniques will be described.

According to the power conversion device disclosed in Unexamined Japanese Patent Publication No. 2010-252461, one of two capacitor terminals is solely disposed between a semiconductor module and a capacitor, and the other capacitor terminal is not sufficiently cooled. Also, in order to increase a thermal contact area between the capacitor terminal and the cooler, the capacitor terminal is extended between the semiconductor module and the capacitor. As a result, there is a new problem that the length of the capacitor terminal is increased, and consequently the inductance is increased.

On the other hand, according to the power conversion device disclosed in Unexamined Japanese Patent Publication No. 2005-73374, a terminal of the semiconductor module protruding from between the refrigerant tubes is connected at a power wiring portion disposed on the terminal, and thus heat dissipation from the terminal to the refrigerant tubes is not enough. Also, the wiring length is increased, causing the inductance to increase.

The present disclosure provides a semiconductor device that suppresses an increase in the temperature of other electronic devices, such as a capacitor, caused by generation of heat by a semiconductor module. There is also provided a semiconductor device that suppresses an increase in the inductance caused by the length of a conductive member between semiconductor modules. The semiconductor device

of the present disclosure may be suitably used for power conversion by an inverter circuit or the like.

Hereinafter, each exemplary embodiment will be described with reference to the drawings.

First Exemplary Embodiment

A configuration of a semiconductor device according to a first exemplary embodiment will be described with reference to FIGS. 1A to 4.

FIG. 1A is a schematic perspective view of the semiconductor device according to the first exemplary embodiment, and FIG. 1B is a schematic side view of the semiconductor device according to the first exemplary embodiment. To facilitate description, package 6 is shown in a manner allowing the structure inside to be seen. Also, coordinate axes are indicated in each drawing. Here, the direction from the bottom to the top of the drawing in FIG. 1A is given as a Z-direction, a longitudinal direction, of the semiconductor device, which is perpendicular to the Z-direction is given as a Y-direction, and the width direction is given as an X-direction. FIG. 1C is a schematic perspective view of a first bus bar of the semiconductor device according to the first exemplary embodiment, and FIG. 1D is a schematic perspective view of a second bus bar of the semiconductor device according to the first exemplary embodiment. FIG. 2A is a schematic cross-sectional view of the semiconductor device according to the first exemplary embodiment, along a line IIA-IIA in FIG. 1B, and FIG. 2B is a schematic cross-sectional view of the semiconductor device according to the first exemplary embodiment, along a line IIB-IIB in FIG. 2A. In FIG. 2B, to facilitate description, positions of semiconductor modules 1 and semiconductor elements 16a, 16b are shown by dotted lines. FIG. 3 is a diagram showing a circuit of the semiconductor device according to the first exemplary embodiment. FIG. 4 is a schematic cross-sectional view of the semiconductor device according to the first exemplary embodiment where arrangement of bus bars is changed, the schematic cross-sectional view showing a position corresponding to the line IIB-IIB in FIG. 2A.

As shown in FIGS. 1A and 1B, the semiconductor device of the present exemplary embodiment has three semiconductor modules 1 and three capacitors 4 for temporarily storing power from a battery disposed next to one another in the Y-direction. Cooling member 2 is disposed between semiconductor modules 1 and capacitors 4, and cooling member 2 includes channel 3 inside. Semiconductor module 1 includes semiconductor elements 16a, 16b (not shown) inside, and since heat is generated at the time of driving of a motor and the like, harmful effect is imposed on peripheral electronic components by the heat. Accordingly, with the semiconductor device of the present exemplary embodiment, cooling member 2 is provided between semiconductor modules 1 and capacitors 4 so that heat from semiconductor modules 1 is absorbed by cooling member 2, and capacitors 4 are prevented from being at a high temperature. Additionally, semiconductor modules 1, capacitors 4, and cooling member 2 are covered by package 6. Package 6 is formed from a sealing resin for sealing semiconductor modules 1, capacitors 4, cooling member 2 and the like, and a case enclosing the sealing resin. As the sealing resin, an epoxy resin, a silicone resin or the like is used, and as the case, one that is obtained by molding a polyphenylenesulfide (PPS) resin or a polybutyleneterephthalate (PBT) resin is used. Additionally, package 6 may be configured by using only the sealing resin and without using the case, or package 6 may be configured with the case formed of a metal material such as aluminum (Al).

Semiconductor module 1 constitutes an inverter circuit for driving a motor, shown in FIG. 3, and includes semiconductor elements 16a, 16b configured from a transistor, such as an IGBT element, and a diode. A connection with a wiring to the motor is disposed between semiconductor element 16a and semiconductor element 16b. Semiconductor element 16b is connected on a negative electrode side of the connection, and semiconductor element 16a is connected on a positive electrode side of the connection. The negative electrode side is referred to as a low side, and the positive electrode side is referred to as a high side. High-side semiconductor element 16a and low-side semiconductor element 16b are paired up. When the motor is driven, power is supplied from high-side semiconductor element 16a, and thus a greater amount of heat is generated by high-side semiconductor element 16a compared with low-side semiconductor element 16b. Therefore, the temperature of high-side semiconductor element 16a becomes higher. As shown in FIG. 1A, three power terminals, namely, power terminal (P terminal) 21a to be connected to high-side semiconductor element 16a, power terminal (N terminal) 21b to be connected to low-side semiconductor element 16b, and power terminal 21c to be connected to the motor, extend from each semiconductor module 1.

As shown in FIGS. 1A and 2A, semiconductor module 1 and capacitor 4 are electrically connected by first bus bar 5a and second bus bar 5b formed by strip-shaped conductive members. First bus bar 5a is connected to P terminal 21a connected to high-side semiconductor element 16a. And second bus bar 5b is connected to N terminal 21b connected to low-side semiconductor element 16b. Also, capacitor 4 includes electrodes on an upper surface and a lower surface, respectively. The electrode on the upper surface of capacitor 4 is connected to first bus bar 5a, and the electrode on the lower surface of capacitor 4 is connected to second bus bar 5b. Here, first bus bar 5a and second bus bar 5b are collectively referred to as bus bars.

Moreover, first bus bar 5a and second bus bar 5b extend through through hole 2a of cooling member 2, and connect capacitor 4 and semiconductor module 1. That is, inside through hole 2a, first bus bar 5a and second bus bar 5b are surrounded by cooling member 2, and first bus bar 5a and second bus bar 5b face cooling member 2 on all of four side aspects. The amount of heat dissipation from the bus bars to cooling member 2 may thus be increased.

As shown in FIGS. 1A and 2A, first bus bar 5a is disposed between cooling member 2 and capacitor 4, and is bent at a right angle near an edge of the upper surface of capacitor 4. First bus bar 5a extends upward to pass through through hole 2a of cooling member 2, and is then connected to P terminal 21a of semiconductor module 1. Also, as shown in FIG. 1C, first bus bar 5a has a part with a width of W1, and a part with a width of W2, which is greater than W1. As shown in FIG. 1B, first bus bar 5a has the width of W1 at a part connected to P terminal 21a of semiconductor module 1 and inside through hole 2a of cooling member 2. And first bus bar 5a has the width of W2, which is greater than W1, between cooling member 2 and capacitor 4. Accordingly, an area of first bus bar 5a facing cooling member 2 is increased, and the amount of heat dissipation from first bus bar 5a to cooling member 2 may be increased.

Furthermore, as shown in FIGS. 1A and 2A, second bus bar 5b is bent at a right angle near an edge of the lower surface of capacitor 4. Second bus bar 5b extends upward to pass through through hole 2a of cooling member 2, and is then connected to N terminal 21b of semiconductor module 1. Also, as shown in FIG. 1D, second bus bar 5b has a part

with a width of $W3$, and a part with a width of $W4$, which is greater than $W3$. As shown in FIG. 1B, second bus bar $5b$ has the width of $W3$ at a part connected to N terminal $21b$ of semiconductor module 1 and inside through hole $2a$ of cooling member 2 . And second bus bar $5b$ has the width of $W4$, which is greater than $W3$, from a bent portion near the lower surface of capacitor 4 to through hole $2a$ of cooling member 2 . That is, second bus bar $5b$ has a third width ($W3$) and a fourth width ($W4$), which is greater than the third width ($W3$) between semiconductor module 1 and capacitor 4 . Accordingly, a heat dissipation area is increased at a part, of second bus bar $5b$, with a wide width, and the amount of heat dissipation from second bus bar $5b$ to package 6 and the like may be increased.

Here, first bus bar $5a$ according to the present exemplary embodiment is an example of a “first conductive member” of the present application, and second bus bar $5b$ is an example of a “second conductive member” of the present application. Also, $W1$ according to the present exemplary embodiment is an example of a “first width” of the present application, and $W2$ is an example of a “second width” of the present application.

Next, an internal structure of the semiconductor device of the present exemplary embodiment will be described in detail with reference to FIGS. 2A and 2B. As shown in FIGS. 2A and 2B, semiconductor module 1 includes inside high-side semiconductor element $16a$ and low-side semiconductor element $16b$. P terminal $21a$ and N terminal $21b$ for power, extending from semiconductor module 1 , are connected to first bus bar $5a$ and second bus bar $5b$, respectively.

First bus bar $5a$ is disposed between capacitor 4 and cooling member 2 , and is connected to the electrode on the upper surface of capacitor 4 . Also, first bus bar $5a$ is bent at a right angle at a position separate from the electrode on the upper surface of capacitor 4 . And first bus bar $5a$ passes through through hole $2a$ of cooling member 2 , and is connected to P terminal $21a$ extending from semiconductor module 1 . Also, second bus bar $5b$ is connected to the electrode on the lower surface of capacitor 4 , and is bent at a right angle at a position separate from the electrode on the lower surface of capacitor 4 . And second bus bar $5b$ passes through through hole $2a$ of cooling member 2 , and is connected to N terminal $21b$ extending from semiconductor module 1 .

Moreover, channel 3 allowing a cooling medium, such as water, ethylene glycol or a refrigerant gas, to flow is formed to cooling member 2 . Channel 3 is curved inside cooling member 2 , and includes flow inlet $3a$ and flow outlet $3b$ on a same side surface of cooling member 2 . Here, semiconductor module 1 is disposed on an upper surface of cooling member 2 so as to be positioned above channel 3 . The amount of heat dissipation from semiconductor module 1 to channel 3 may thereby be increased. Also, high-side semiconductor element $16a$ is disposed above channel 3 , on a side nearer to flow inlet $3a$. A cooling medium flowing through channel 3 absorbs heat and has its temperature increased while flowing from flow inlet $3a$ to flow outlet $3b$. Accordingly, a cooling medium nearer to flow inlet $3a$ has a lower temperature, and may absorb a greater amount of heat. As described above, since high-side semiconductor element $16a$ generates more heat, an increase in the temperature of semiconductor module 1 may be suppressed by disposing high-side semiconductor element $16a$ above channel 3 , on the side nearer to flow inlet $3a$.

As described above, first bus bar $5a$ and second bus bar $5b$ pass through through hole $2a$ of cooling member 2 , and connect semiconductor module 1 and capacitor 4 . With the

bus bars configured to pass near cooling member 2 , heat dissipation from the bus bars to cooling member 2 may be promoted, and heat transferred from semiconductor module 1 to capacitor 4 may be reduced by the bus bars.

As shown in FIG. 2B, cross sections of first bus bar $5a$ and second bus bar $5b$ each have a rectangular shape, and have a first side surface corresponding to a long side of the rectangle and a second side surface corresponding to a short side of the rectangle. Since the first side surfaces have larger areas, first bus bar $5a$ and second bus bar $5b$ are disposed with the first side surfaces facing the part, of cooling member 2 , where channel 3 is provided. Accordingly, compared to a case where the second side surfaces with smaller areas face the part, of cooling member 2 , where channel 3 is provided, the amount of heat dissipation from first bus bar $5a$ and second bus bar $5b$ to cooling member 2 is increased. Here, first bus bar $5a$ and second bus bar $5b$ are disposed next to each other, along a direction parallel to a direction of channel 3 . When disposed in this manner, first bus bar $5a$ and second bus bar $5b$ may face the part, of cooling member 2 , where channel 3 is provided, with nothing between the bus bars and cooling member 2 , and thus a greater amount of heat may be dissipated to cooling member 2 .

On the other hand, as shown in FIG. 4, first bus bar $5a$ and second bus bar $5b$ may be disposed with the first side surfaces overlapping each other. When disposed in this manner, the cooling effect may be reduced but an increase in inductance may be suppressed compared to the case where first bus bar $5a$ and second bus bar $5b$ are disposed next to each other, along the direction parallel to the direction of channel 3 . Mutual inductance of adjacent current paths is given by Lenz’s law, and inductance is cancelled by first bus bar $5a$ and second bus bar $5b$ whose currents are in opposite directions. In the present exemplary embodiment, since the first side surfaces, which are the larger side surfaces, of first bus bar $5a$ and second bus bar $5b$ face each other, greater inductance is cancelled. Thus, an increase in the inductance of the entire semiconductor device may be suppressed.

As described above, by causing first bus bar $5a$ and second bus bar $5b$ to pass through through hole $2a$ of cooling member 2 , transfer of heat from semiconductor module 1 to capacitor 4 may be suppressed. Thus, an increase in the temperature of capacitor 4 may be suppressed. In addition, by providing a wide part to first bus bar $5a$, which is connected to high-side semiconductor element $16a$ generating a great amount of heat, and disposing the wide part between cooling member 2 and capacitor 4 , the amount of heat dissipation to cooling member 2 may be increased. Also, by providing a wide part to second bus bar $5b$ not disposed between cooling member 2 and capacitor 4 , the amount of heat dissipation from second bus bar $5b$ to package 6 and the like may be increased because a heat dissipation area may be increased. Accordingly, an increase in the temperature of capacitor 4 may be further suppressed.

Additionally, a film capacitor with a high insulation property may be used as capacitor 4 of the present exemplary embodiment. A film capacitor has a structure where metal foils as a cathode and an anode are formed and wound around a plastic film or the like.

Here, capacitor 4 according to the present exemplary embodiment is an example of a “passive element” of the present application. Additionally, other than capacitor 4 , the “passive element” of the present application includes a reactor and the like.

As described above, the semiconductor device according to the present exemplary embodiment may increase the amount of heat dissipation from first bus bar $5a$ and second

bus bar **5b** by causing first bus bar **5a** and second bus bar **5b** to pass through through hole **2a** of cooling member **2**, disposing first bus bar **5a** between cooling member **2** and capacitor **4**, and providing a wide part to second bus bar **5b**. Accordingly, transfer of heat from semiconductor module **1** to capacitor **4** may be suppressed, and an increase in the temperature of capacitor **4** due to heat generation by semiconductor module **1** may be suppressed.

Second Exemplary Embodiment

A configuration of a semiconductor device according to a second exemplary embodiment will be described with reference to FIGS. **5A** and **5B**. FIG. **5A** is a schematic cross-sectional view of the semiconductor device according to the second exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. **1B**, and FIG. **5B** is a schematic cross-sectional view of the semiconductor device according to the second exemplary embodiment, along a line VB-VB in FIG. **5A**. As shown in FIGS. **5A** and **5B**, according to the semiconductor device of the second exemplary embodiment, first bus bars **5a** and second bus bars **5b** extend through cut-out portions **2b** provided to cooling member **2**. Other configurations are the same as those in the first exemplary embodiment.

According to the present exemplary embodiment, first bus bar **5a** and second bus bar **5b** face cooling member **2** at three side aspects other than an opening direction of cut-out portion **2b**. Accordingly, the amount of heat dissipation from the bus bars may be increased. Also, compared to a case where through holes **2a** are formed to cooling member **2**, the width of cooling member **2** may be reduced, and the semiconductor device may be miniaturized.

Third Exemplary Embodiment

A configuration of a semiconductor device according to a third exemplary embodiment will be described with reference to FIGS. **6A** and **6B**. FIG. **6A** is a schematic cross-sectional view of the semiconductor device according to the third exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. **1B**, and FIG. **6B** is a schematic cross-sectional view of the semiconductor device according to the third exemplary embodiment, along a line VIB-VIB in FIG. **6A**. As shown in FIGS. **6A** and **6B**, according to the semiconductor device of the third exemplary embodiment, through holes **2a** are not formed to cooling member **2**, and first bus bars **5a** and second bus bars **5b** do not pass through through holes **2a** of cooling member **2**. Moreover, another cooling member **2** is provided adjacent to first bus bars **5a** and second bus bars **5b**, and first bus bars **5a** and second bus bars **5b** are disposed such that first bus bars **5a** and second bus bars **5b** are interposed between two cooling members **2**. Other configurations are the same as those in the first exemplary embodiment.

According to the present exemplary embodiment, first bus bars **5a** and second bus bars **5b** face both of two cooling members **2** disposed on both sides, at the first side surfaces with large areas. That is, first bus bars **5a** and second bus bars **5b** each face cooling members **2** at two side surfaces. Accordingly, the amount of heat dissipation from the bus bars to cooling members **2** may be increased, as in a case where the bus bars are disposed inside through holes **2a** of cooling member **2**. Moreover, cooling members **2** on both sides of the bus bars include channel **3** for allowing a cooling medium to flow. Accordingly, cooling members **2** on both sides of the bus bars may be maintained at a low temperature, and the amount of heat dissipation from the bus bars to cooling member **2** may be increased. An increase in the temperature of capacitor **4** may thereby be suppressed.

Fourth Exemplary Embodiment

A configuration of a semiconductor device according to a fourth exemplary embodiment will be described with reference to FIGS. **7A** and **7B**. FIG. **7A** is a schematic cross-sectional view of the semiconductor device according to the fourth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. **1B**, and FIG. **7B** is a schematic cross-sectional view of the semiconductor device according to the fourth exemplary embodiment, along a line VIIB-VIIB in FIG. **7A**. As shown in FIGS. **7A** and **7B**, according to the semiconductor device of the fourth exemplary embodiment, channels **3** inside cooling member **2** are not curved inside cooling member **2**, and include flow inlets **3a** at one side surface of cooling member **2**, and flow outlets **3b** at an opposite side surface. That is, a cooling medium flows in one direction through the inside of cooling member **2**, and does not return to the side surface where flow inlets **3a** are present. Also, one each of channels **3** is provided below high-side semiconductor element **16a** inside semiconductor module **1**, and another each of channels **3** is provided below low-side semiconductor element **16b** inside semiconductor module **1**. Other configurations are the same as those in the first exemplary embodiment.

According to the present exemplary embodiment, since a plurality of channels **3** are formed to cooling member **2**, the cooling capacity is high. Thus, the amount of heat dissipation from semiconductor modules **1**, the bus bars, and capacitors **4** may be increased. Moreover, since channel **3** is provided below each of high-side semiconductor elements **16a** and low-side semiconductor elements **16b** inside semiconductor modules **1**, the temperature of a cooling medium flowing below low-side semiconductor element **16b** may be reduced. Consequently, the amount of heat dissipation from semiconductor modules **1** may be increased.

Fifth Exemplary Embodiment

A configuration of a semiconductor device according to a fifth exemplary embodiment will be described with reference to FIGS. **8A** and **8B**. FIG. **8A** is a schematic cross-sectional view of the semiconductor device according to the fifth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. **1B**, and FIG. **8B** is a schematic cross-sectional view of the semiconductor device according to the fifth exemplary embodiment, along a line VIIIB-VIIIB in FIG. **8A**. As shown in FIGS. **8A** and **8B**, according to the semiconductor device of the fifth exemplary embodiment, fins **7** for increasing a heat dissipation area are provided inside channel **3** of cooling member **2**. Fins **7** are provided below semiconductor modules **1**. Other configurations are the same as those in the first exemplary embodiment.

According to the present exemplary embodiment, the amount of heat dissipation from cooling member **2** to a cooling medium is increased by fins **7**. Furthermore, because fins **7** are provided below semiconductor modules **1**, heat dissipation particularly from semiconductor modules **1** may be promoted.

Sixth Exemplary Embodiment

A configuration of a semiconductor device according to a sixth exemplary embodiment will be described with reference to FIGS. **9A** and **9B**. FIG. **9A** is a schematic cross-sectional view of the semiconductor device according to the sixth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. **1B**, and FIG. **9B** is a schematic cross-sectional view of the semiconductor device according to the sixth exemplary embodiment, along a line IXB-IXB in FIG. **9A**. As shown in FIGS. **9A** and **9B**, according to the semiconductor device of the sixth exemplary embodiment, fins **7** are provided inside channel **3** of cooling member **2**, near a curved portion of channel **3**, so as to control a

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direction of flow of a cooling medium so that the flow of a cooling medium is directed toward a center side of the curve. Other configurations are the same as those in the first exemplary embodiment.

When a cooling medium flows through the curved portion inside channel 3 of cooling member 2, the water pressure is reduced on the inside of the curve by a centrifugal force, and bubbles are generated. When bubbles are generated, transfer of heat from cooling member 2 to the cooling medium is suppressed, and thus the heat dissipation effect is reduced.

According to the present exemplary embodiment, because the flow of the cooling medium may be directed toward the center side of the curve by fins 7, bubbles may be suppressed at the time of the cooling medium flowing through the curved portion. Accordingly, reduction in the amount of heat dissipation from cooling member 2 to the cooling medium may be suppressed.

Seventh Exemplary Embodiment

A configuration of a semiconductor device according to a seventh exemplary embodiment will be described with reference to FIG. 10. FIG. 10 is a schematic cross-sectional view of the semiconductor device according to the seventh exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B. As shown in FIG. 10, according to the semiconductor device of the seventh exemplary embodiment, two channels 3 (not shown) are provided inside cooling member 2, and flow inlet 3a and flow outlet 3b of each channel are disposed next to each other in the Z-direction. That is, according to the semiconductor device of the seventh exemplary embodiment, unlike in the first exemplary embodiment, channels 3 provided to cooling member 2 are curved in a vertical direction (on a Y-Z plane). A cooling medium flows from flow inlet 3a provided on a side surface of cooling member 2 into channel 3 on the upper surface (the surface where semiconductor module 1 is disposed) side of cooling member 2. And the cooling medium enters channel 3 on a lower surface side of cooling member 2 at the curved portion of channel 3, and then returns to flow outlet 3b provided on the same side surface of cooling member 2. Also, channel 3 is provided below each of high-side semiconductor element 16a and low-side semiconductor element 16b inside semiconductor module 1. Other configurations are the same as those in the first exemplary embodiment.

According to the present exemplary embodiment, because a plurality of channels 3 are formed to cooling member 2, the cooling capacity is high. Thus, the amount of heat dissipation from semiconductor modules 1, the bus bars, and capacitors 4 may be increased. Also, since channels 3 near flow inlets 3a are disposed on a side closer to the surface where semiconductor modules 1 are disposed, the amount of heat dissipation from semiconductor modules 1 may be increased.

Eighth Exemplary Embodiment

A configuration of a semiconductor device according to an eighth exemplary embodiment will be described with reference to FIGS. 11A and 11B. FIG. 11A is a schematic cross-sectional view of the semiconductor device according to the eighth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B, and FIG. 11B is a schematic cross-sectional view of the semiconductor device according to the eighth exemplary embodiment, along a line XIB-XIB in FIG. 11A. As shown in FIGS. 11A and 11B, according to the semiconductor device of the eighth exemplary embodiment, capacitors 4 are disposed with the electrodes of capacitors 4 positioned on both side surfaces. Also, first bus bars 5a and second bus bars 5b connected to

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respective electrodes of capacitors 4 are separated to respective sides of cooling member 2. And first bus bars 5a and second bus bars 5b connect capacitors 4 and semiconductor modules 1. That is, cooling member 2 and semiconductor modules 1 are disposed between first bus bars 5a and second bus bars 5b. Through holes 2a are not provided to cooling member 2. Other configurations are the same as those in the first exemplary embodiment.

According to the present exemplary embodiment, first bus bars 5a and second bus bars 5b connected to respective sides of capacitors 4 are connected to semiconductor modules 1 without passing through between capacitors 4 and cooling member 2. Accordingly, since lengths of bus bars between capacitors 4 and semiconductor modules 1 may be reduced, an increase in the inductance due to lengths of conductive members may be suppressed to the minimum. Also, since cooling member 2 is not disposed outside first bus bars 5a and second bus bars 5b, the semiconductor device may be miniaturized.

Also, according to the present exemplary embodiment, first bus bars 5a connected to high-side semiconductor elements 16a that generate a great amount of heat are disposed near channel 3 of cooling member 2, on the side of flow inlet 3a. That is, first bus bars 5a whose temperatures become high are placed near channel 3, on the side of flow inlet 3a where the temperature of the cooling medium is low, and first bus bars 5a are made to face cooling member 2. Accordingly, the amount of heat dissipation from the bus bars may be increased, and an increase in the temperature of capacitors 4 may be suppressed.

Additionally, in the present exemplary embodiment, first bus bars 5a and second bus bars 5b may include wide parts, as in the first exemplary embodiment, at arbitrary positions between capacitors 4 and semiconductor modules 1. Alternatively, first bus bars 5a and second bus bars 5b may have a wide width in entire portion between capacitors 4 and semiconductor modules 1. The amount of heat dissipation from the bus bars may thereby be increased.

Ninth Exemplary Embodiment

A configuration of a semiconductor device according to a ninth exemplary embodiment will be described with reference to FIGS. 12A and 12B. FIG. 12A is a schematic cross-sectional view of the semiconductor device according to the ninth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. 1B, and FIG. 12B is a schematic cross-sectional view of the semiconductor device according to the ninth exemplary embodiment, along a line XIIB-XIIB in FIG. 12A. As shown in FIGS. 12A and 12B, according to the semiconductor device of the ninth exemplary embodiment, through holes 2a are provided to cooling member 2, and first bus bars 5a extend through through holes 2a of cooling member 2. And first bus bars 5a connect capacitors 4 and semiconductor modules 1. Also, as in the eighth exemplary embodiment, first bus bars 5a are disposed near channel 3 of cooling member 2, on the side of flow inlet 3a. Other configurations are the same as those in the eighth exemplary embodiment.

According to the present exemplary embodiment, first bus bars 5a are connected to P terminals 21a from high-side semiconductor elements 16a whose temperature tends to be increased. Thus, in order to suppress transfer of heat from semiconductor modules 1 to capacitors 4, the amount of heat dissipation from first bus bars 5a is desirably increased. On the other hand, second bus bars 5b are connected to N terminals 21b from low-side semiconductor elements 16b whose temperature tends to be lower than that of high-side

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semiconductor elements **16a**. Thus, the amount of heat dissipation from second bus bars **5b** should be small.

Accordingly, in the present exemplary embodiment, by passing first bus bars **5a** through through holes **2a** of cooling member **2**, the amount of heat dissipation from first bus bars **5a**, which is connected to P terminals **21a** of high-side semiconductor elements **16a** generating a great amount of heat, may be increased.

Tenth Exemplary Embodiment

A configuration of a semiconductor device according to a tenth exemplary embodiment will be described with reference to FIGS. **13A** and **13B**. FIG. **13A** is a schematic cross-sectional view of the semiconductor device according to the tenth exemplary embodiment, at a position corresponding to the line IIA-IIA in FIG. **1B**, and FIG. **13B** is a schematic cross-sectional view of the semiconductor device according to the tenth exemplary embodiment, along a line XIIIIB-XIIIIB in FIG. **13A**. As shown in FIGS. **13A** and **13B**, according to the semiconductor device of the tenth exemplary embodiment, through holes **2a** are provided on both sides of cooling member **2**. And each of first bus bars **5a** and second bus bars **5b** extends through through hole **2a** of cooling member **2**, and connects capacitors **4** and semiconductor modules **1**. As in the eighth exemplary embodiment, first bus bars **5a** are disposed near channel **3** of cooling member **2**, on the side of flow inlet **3a**. Other configurations are the same as those in the eighth exemplary embodiment.

According to the present exemplary embodiment, each of first bus bars **5a** and second bus bars **5b** is cooled in through hole **2a** of cooling member **2**, and thus the amount of heat dissipation from the bus bars may be increased.

Various alterations may be made to the configurations of the first to the tenth exemplary embodiments described above. Such variations will be described below.

First Variation

A configuration of a semiconductor device according to a first variation will be described with reference to FIGS. **14A** and **14B**. FIG. **14A** is a schematic view of a capacitor according to the first variation, and FIG. **14B** is an explanatory structural view of the capacitor according to the first variation. As described in the first exemplary embodiment, film capacitors are used as capacitors **4** in the exemplary embodiments described above. Capacitors **4** of the exemplary embodiments described above are not provided with a winding shaft at a center, but in the present variation, a rod made of a highly thermal conductive material is used as core rod **10**, as shown in FIG. **14A**, so as to increase heat dissipation from capacitor **4**. As the material of core rod **10**, a metal material, such as aluminum, a ceramic material or the like may be used.

Next, a structure of capacitor **4** (film capacitor) according to the present variation will be described with reference to FIG. **14B**. As shown in FIG. **14B**, capacitor **4** of the present variation has metal thin film **14** of aluminum or the like formed on a surface on one side of insulation film **13** of plastic or the like. Also, to increase heat dissipation, highly thermal conductive carbon sheet **15** is disposed on metal thin film **14**. Capacitor **4** shown in FIG. **14A** is formed by stacking two laminated bodies, each including insulation film **13**, metal thin film **14**, and carbon sheet **15**, and winding the same around core rod **10**. Here, the laminated bodies of insulation film **13**, metal thin film **14**, and carbon sheet **15** are overlapped while being shifted from each other. And metal thin films **14** on protruding sides are connected to anode extraction electrode **11** and cathode extraction electrode **12**, respectively. Accordingly, insulation film **13** is interposed between metal thin film **14** connected to anode

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extraction electrode **11** and metal thin film **14** connected to cathode extraction electrode **12** so as to function as a capacitor.

In the present exemplary embodiment, since core rod **10** and carbon sheet **15** with high thermal conductivity are used, heat is easily transferred from capacitors **4**. Thus, an increase in the temperature of capacitor **4** may be prevented.

Second Variation

A configuration of a semiconductor device according to a second variation will be described with reference to FIGS. **15A** and **15B**. FIG. **15A** is a schematic cross-sectional view of the semiconductor device according to the second variation, at a position corresponding to the line IIA-IIA in FIG. **1B**, and FIG. **15B** is a schematic locally-enlarged view of semiconductor elements and their surroundings (part A in FIG. **15A**). As shown in FIG. **15B**, according to the semiconductor device of the second variation, semiconductor module **1** includes semiconductor elements **16a**, **16b** and base substrate **17**. Semiconductor elements **16a**, **16b** are fixed on base substrate **17**. Semiconductor elements **16a**, **16b** and base substrate **17** are disposed on cooling member **2**, and protrusions and recesses are formed on a surface of base substrate **17**, on the side of cooling member **2**. Also, thermal conductive member **18**, such as highly thermal conductive grease or adhesive or a highly thermal conductive sheet, is inserted between base substrate **17** and cooling member **2**. Other configurations are the same as those in the first exemplary embodiment.

Heat generated by semiconductor elements **16a**, **16b** is transmitted to cooling member **2** through base substrate **17** and thermal conductive member **18**.

In the present exemplary embodiment, thermal conductive member **18** is inserted between base substrate **17** and cooling member **2**. Thus, a layer of air generated between base substrate **17** and cooling member **2** is reduced, and the amount of heat dissipation from base substrate **17** to cooling member **2** is increased. Furthermore, since protrusions and recesses are formed on the surface of base substrate **17**, on the side of cooling member **2**, the amount of heat dissipation to thermal conductive member **18** is further increased. Thus, a great amount of heat is allowed to flow to cooling member **2**.

Eleventh Exemplary Embodiment

A configuration of a semiconductor device according to an eleventh exemplary embodiment will be described with reference to FIGS. **16A** to **19**. FIG. **16A** is a perspective view of the semiconductor device according to the eleventh exemplary embodiment, seen from above, and FIG. **16B** is a perspective view of the semiconductor device according to the eleventh exemplary embodiment, seen from below. FIG. **17** is a perspective view of a semiconductor module according to the eleventh exemplary embodiment. Also, FIG. **18** is a schematic view describing connection between semiconductor modules according to the eleventh exemplary embodiment, and FIG. **19** is a diagram showing a circuit of the semiconductor device according to the eleventh exemplary embodiment.

In the present exemplary embodiment, high-side semiconductor element **16a** and low-side semiconductor element **16b** are formed as separate modules. That is, the semiconductor device of the present exemplary embodiment includes semiconductor module **1** in which high-side semiconductor element **16a** is incorporated (hereinafter referred to as "high-side semiconductor module **1a**") and semiconductor module **1** in which low-side semiconductor element **16b** is incorporated (hereinafter referred to as "low-side semiconductor module **1b**"). Accordingly, the degree of

freedom regarding arrangement of semiconductor modules **1** inside the semiconductor device and regarding circuit configuration may be increased. Here, high-side semiconductor element **16a** according to the present exemplary embodiment is an example of a “first semiconductor element” of the present application, and high-side semiconductor module **1a** is an example of a “first semiconductor element module” of the present application. Also, low-side semiconductor element **16b** according to the present exemplary embodiment is an example of a “second semiconductor element” of the present application, and low-side semiconductor module **1b** is an example of a “second semiconductor element module” of the present application.

As shown in FIG. **16A**, high-side semiconductor module **1a** and low-side semiconductor module **1b** are disposed side by side (in the X-direction) on a side surface of cooling member **2**. Also, three sets of high-side semiconductor module **1a** and low-side semiconductor module **1b** are disposed alternately with cooling members **2**. Also, all of high-side semiconductor modules **1a** are disposed in the same direction (left direction) with respect to low-side semiconductor modules **1b**.

As in the case of cooling members **2** described in the first exemplary embodiment and the like, channel **3** (not shown) for allowing a cooling medium to flow is formed inside cooling member **2** of the present exemplary embodiment. A cooling medium flows in from flow inlet **3a** formed on a side surface of cooling member **2**. The cooling medium passes through channel **3** inside, and flows out from flow outlet **3b** formed on an opposite side surface of cooling member **2**. Flow inlet **3a** for a cooling medium is formed on a side surface, of cooling member **2**, nearer to high-side semiconductor module **1a**. Though, as in the fourth exemplary embodiment, a shape of channel **3** of cooling member **2** according to the present exemplary embodiment is straight, channel **3** may be shaped to have a curved portion as in the first exemplary embodiment.

Also, as shown in FIG. **16B**, high-side semiconductor module **1a** and low-side semiconductor module **1b** are electrically connected to each other by P terminal **21a**, N terminal **21b** protruding from semiconductor modules **1**.

P terminal **21a**, N terminal **21b** protruding from semiconductor module **1** will be described with reference to FIG. **17**. Here, for the sake of explanation, high-side semiconductor module **1a** will be described as a representative example. As shown in FIG. **17**, P terminal **21a** and N terminal **21b**, which are connected to high-side semiconductor element **16a** inside and each has a metal plate shape, protrude from side surfaces of high-semiconductor module **1a**. Also, signal terminals **22** for control protrude from a side surface. Among P terminal **21a** and N terminal **21b**, P terminal **21a**, which is connected to a positive electrode side, protrudes in a direction orthogonal to a protruding direction of signal terminals **22**, and N terminal **21b**, which is connected to a negative electrode side, protrudes in a direction opposite the protruding direction of signal terminals **22**. After P terminal **21a** protrudes in the direction orthogonal to the protruding direction of signal terminals **22**, P terminal **21a** is bent at a right angle, and extends in a protruding direction of N terminal **21b**. On the other hand, after N terminal **21b** protrudes in the direction opposite the protruding direction of signal terminals **22**, N terminal **21b** is bent at a right angle, and extends in a direction opposite a protruding direction of P terminal **21a**.

With P terminal **21a** and N terminal **21b** shaped in the above manner, high-side semiconductor module **1a** and low-side semiconductor module **1b** may be disposed next to

each other, and tip ends of P terminal **21a** and N terminal **21b** may be made to overlap each other at outside cooling member **2**, as shown in FIG. **16B**. Since through holes are formed to the tip ends of P terminals **21a** and N terminals **21b**, circuit for driving a motor, as shown in FIG. **19**, may be formed by electrical connection by a metal rod or the like passing through the through holes. Also, since the terminals may be directly connected to each other in the above manner, an increase in the inductance caused by wiring connecting semiconductor modules **1** may be suppressed.

Here, P terminal **21a** according to the present exemplary embodiment is an example of a “first power terminal” and a “third power terminal” of the present application, and N terminal **21b** is an example of a “second power terminal” and a “fourth power terminal” of the present application.

Connection between high-side semiconductor module **1a** and low-side semiconductor module **1b** will be described in detail with reference to FIG. **18**. As described above, high-side semiconductor module **1a** and low-side semiconductor module **1b** are disposed side by side (in the X-direction) on side surfaces of cooling members **2**. Here, high-side semiconductor module **1a** and low-side semiconductor module **1b** are disposed with large surfaces (upper and lower surfaces) in contact with cooling members **2**. Accordingly, the amount of heat dissipation from semiconductor module **1** to cooling members **2** may be increased, and an increase in the temperature of semiconductor module **1** may be suppressed.

N terminal **21b** of high-side semiconductor module **1a** is bent toward low-side semiconductor module **1b**. On the other hand, P terminal **21a** of low-side semiconductor module **1b** protrudes toward high-side semiconductor module **1a**, and is bent downward (in a direction opposite an arrow in the Z-direction). Accordingly, the tip end of N terminal **21b** of high-side semiconductor module **1a** and the tip end of P terminal **21a** of low-side semiconductor module **1b** may be disposed overlapping each other.

Here, P terminal **21a** protrudes from semiconductor module **1**, in parallel to a direction in which semiconductor modules **1** are disposed next to each other (X-direction). That is, P terminal **21a** protrudes at a position facing the side surfaces of cooling members **2**. Accordingly, the amount of heat dissipation from a protruding portion of P terminal **21a** to cooling members **2** is increased, and an increase in the temperature of semiconductor module **1** may be suppressed.

As described above, according to the semiconductor device of the present exemplary embodiment, a plurality of semiconductor modules **1** are disposed on cooling members **2**, and the power terminals (P terminal **21a**, N terminal **21b**) of semiconductor modules **1** are directly connected so as to suppress an increase in the inductance due to wiring and to suppress an increase in the temperature of semiconductor modules **1**.

Twelfth Exemplary Embodiment

A configuration of a semiconductor device according to a twelfth exemplary embodiment will be described with reference to FIG. **20**. FIG. **20** is a schematic view describing connection between semiconductor modules according to the twelfth exemplary embodiment. As shown in FIG. **20**, the shape of N terminal **21b** of semiconductor module **1** according to the twelfth exemplary embodiment is different from that of semiconductor module **1** according to the eleventh exemplary embodiment. N terminal **21b** of semiconductor module **1** according to the present exemplary embodiment protrudes in a direction orthogonal to the protruding direction (Z-direction) of signal terminals **22** and in a direction (X-direction) opposite the protruding direction

of P terminal **21a**. Other configurations are the same as those in the eleventh exemplary embodiment.

According to such a configuration, by disposing high-side semiconductor module **1a** and low-side semiconductor module **1b** at predetermined positions, a bent portion of P terminal **21a** and the tip end of N terminal **21b** may be made to overlap each other. Accordingly, connection may be easily achieved by electrically connecting the overlapped portions of P terminal **21a** and N terminal **21b**.

Also, compared to semiconductor module **1** according to the eleventh exemplary embodiment, the wiring for connecting semiconductor modules **1** may be reduced. An increase in the inductance due to wiring may thereby be further suppressed.

Furthermore, N terminal **21b** protrudes from semiconductor module **1**, in parallel to the direction in which semiconductor modules **1** are disposed next to each other. Accordingly, a protruding portion of N terminal **21b** is disposed facing the side surfaces of cooling members **2**. The amount of heat dissipation from the protruding portion of N terminal **21b** to cooling members **2** may thereby be increased.

Additionally, high-side semiconductor modules **1a** may be electrically connected by connecting the tip ends of P terminals **21a** outside cooling members **2**, as in the eleventh exemplary embodiment.

Thirteenth Exemplary Embodiment

A configuration of a semiconductor device according to a thirteenth exemplary embodiment will be described with reference to FIGS. **21A** and **21B**. FIG. **21A** is a schematic side view of the semiconductor device according to the thirteenth exemplary embodiment, and FIG. **21B** is a schematic bottom view of the semiconductor device according to the thirteenth exemplary embodiment. As shown in FIGS. **21A** and **21B**, according to the semiconductor device of the thirteenth exemplary embodiment, high-side semiconductor module **1a** and low-side semiconductor module **1b** are disposed facing each other across cooling member **2**. That is, high-side semiconductor module **1a** is disposed on one side surface of cooling member **2**, and low-side semiconductor module **1b** is disposed on the other surface (on the opposite side from the one side surface) of cooling member **2**.

Moreover, high-side semiconductor module **1a** and low-side semiconductor module **1b** are disposed in such a way that protruding directions of P terminals **21a** are opposite each other. That is, P terminal **21a** of high-side semiconductor module **1a** protrudes to the left side in the drawing, and P terminal **21a** of low-side semiconductor module **1b** protrudes to the right side in the drawing. Accordingly, as shown in FIG. **21B**, N terminal **21b** of high-side semiconductor module **1a** and P terminal **21a** of low-side semiconductor module **1b** may be electrically connected by conductive terminal connection rod **23**.

Furthermore, as shown in FIG. **21B**, channel **3** curved inside cooling member **2** is formed inside cooling member **2**. Channel **3** includes flow inlet **3a** on a side surface where high-side semiconductor module **1a** is disposed and flow outlet **3b** on a side surface where low-side semiconductor module **1b** is disposed. Accordingly, since a low-temperature cooling medium entering from flow inlet **3a** is allowed to flow through channel **3** near high-side semiconductor module **1a**, which generates a great amount of heat, the amount of heat dissipation from high-side semiconductor module **1a** may be increased.

As described above, according to the semiconductor device of the present exemplary embodiment, a set of high-side semiconductor module **1a** and low-side semiconductor module **1b** are compactly integrated with cooling

member **2**, and by combining such sets, an inverter circuit for driving a motor may be configured, for example.

Fourteenth Exemplary Embodiment

A configuration of a semiconductor device according to a fourteenth exemplary embodiment will be described with reference to FIGS. **22A** and **22B**. FIG. **22A** is a schematic side view of the semiconductor device according to the fourteenth exemplary embodiment, and FIG. **22B** is a schematic bottom view of the semiconductor device according to the fourteenth exemplary embodiment. As shown in FIG. **22B**, according to the semiconductor device of the fourteenth exemplary embodiment, two channels **3** having straight shapes formed to cooling member **2**. Each of channels **3** does not include a curved portion. A cooling medium flows straight, in one direction, from one side surface to the other side surface of cooling member **2**. Other configurations are the same as those in the thirteenth exemplary embodiment.

Moreover, the direction of flow of a cooling medium is different between one channel **3** near the side surface where high-side semiconductor module **1a** is disposed and the other channel **3** near the side surface where low-side semiconductor module **1b** is disposed.

In the present exemplary embodiment, since a plurality of channels **3** are formed to cooling member **2**, the cooling capacity is high. Thus, the amount of heat dissipation from semiconductor module **1** may be increased. A downstream side, of one channel, where the temperature of a cooling medium is high is an upstream side of the other channel, and thus high cooling capacity may be achieved on both the upstream sides and the downstream sides of channels **3** of cooling member **2**.

Fifteenth Exemplary Embodiment

A configuration of a semiconductor device according to a fifteenth exemplary embodiment will be described with reference to FIG. **23**. FIG. **23** is a schematic side view of the semiconductor device according to the fifteenth exemplary embodiment. As shown in FIG. **23**, according to the semiconductor device of the fifteenth exemplary embodiment, three sets of high-side semiconductor module **1a** and low-side semiconductor module **1b** (not shown) of the thirteenth exemplary embodiment are arranged side by side (in the X-direction) for common cooling member **2**.

In the present exemplary embodiment, compared to a case where three semiconductor devices of the thirteenth exemplary embodiment are coupled, semiconductor modules **1** may be cooled by one cooling member **2**. Thus, the structure is simplified, and also electrical connection between semiconductor modules **1** is facilitated.

Additionally, additional cooling members **2** may be disposed on outside of high-side semiconductor module **1a** and outside of low-side semiconductor module **1b**, as in the thirteenth exemplary embodiment. The amount of heat dissipation from semiconductor modules **1** may thereby be further increased, and an increase in the temperature of semiconductor modules **1** may be suppressed.

The semiconductor device according to the present disclosure has been described based on exemplary embodiments, but the present disclosure is not limited to the above-described exemplary embodiments. The technology of the present disclosure may be applied to other exemplary embodiments realized by combining constitutional elements of each of the exemplary embodiments, to variations obtained by making, to each exemplary embodiment, various alterations conceived by a person skilled in the art without departing from the spirit of the present disclosure,

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and to various appliances and systems in which the semiconductor devices of the present disclosure are incorporated.

For example, in the thirteenth to the fifteenth exemplary embodiments, two channels **3** may be vertically formed in cooling member **2**, as in the eleventh exemplary embodiment.

The semiconductor device according to the present disclosure is useful mainly as a high-power semiconductor device for driving an electric motor of an electric car or a hybrid car, for example.

What is claimed is:

1. A semiconductor device comprising:

a semiconductor module including a semiconductor element;

a passive element;

a cooling member disposed between the semiconductor module and the passive element; and

a first conductive member and a second conductive member for electrically connecting the semiconductor module and the passive element, wherein:

two or more aspects of at least one of the first conductive member and the second conductive member face the cooling member,

the cooling member includes a through hole, and at least one of the first conductive member and the second conductive member extends through the through hole of the cooling member.

2. A semiconductor device comprising:

a semiconductor module including a semiconductor element;

a passive element;

a cooling member disposed between the semiconductor module and the passive element; and

a first conductive member and a second conductive member for electrically connecting the semiconductor module and the passive element, wherein:

two or more aspects of at least one of the first conductive member and the second conductive member face the cooling member,

the cooling member includes a cut-out portion, and at least one of the first conductive member and the second conductive member extends through the cut-out portion of the cooling member.

3. A semiconductor device comprising:

a semiconductor module including a semiconductor element;

a passive element;

a cooling member disposed between the semiconductor module and the passive element; and

a first conductive member and a second conductive member for electrically connecting the semiconductor module and the passive element, wherein:

two or more aspects of at least one of the first conductive member and the second conductive member face the cooling member,

the cooling member is configured from a first cooling member and a second cooling member, and

at least one of the first conductive member and the second conductive member is disposed between the first cooling member and the second cooling member.

4. A semiconductor device comprising:

a semiconductor module including a semiconductor element;

a passive element;

a cooling member disposed between the semiconductor module and the passive element; and

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a first conductive member and a second conductive member for electrically connecting the semiconductor module and the passive element, wherein:

two or more aspects of at least one of the first conductive member and the second conductive member face the cooling member, and

the first conductive member at least includes a part with a first width and a part with a second width greater than the first width, the part with the second width being disposed between the cooling member and the passive element.

5. A semiconductor device comprising:

a semiconductor module including a semiconductor element;

a passive element;

a cooling member disposed between the semiconductor module and the passive element; and

a first conductive member and a second conductive member for electrically connecting the semiconductor module and the passive element, wherein:

two or more aspects of at least one of the first conductive member and the second conductive member face the cooling member,

the cooling member includes a channel for allowing a cooling medium to flow,

the channel includes a curved portion, and a flow inlet of the channel and a flow outlet of the channel are disposed on one side surface of the cooling member.

6. A semiconductor device comprising:

a semiconductor module including a semiconductor element;

a passive element;

a cooling member disposed between the semiconductor module and the passive element; and

a first conductive member and a second conductive member for electrically connecting the semiconductor module and the passive element, wherein:

two or more aspects of at least one of the first conductive member and the second conductive member face the cooling member,

the cooling member includes a channel for allowing a cooling medium to flow,

a flow inlet of the channel is disposed on one side surface of the cooling member, and

a flow outlet of the channel is disposed on the other side surface that is opposite the one side surface of the cooling member.

7. The semiconductor device according to claim **1**, wherein:

the passive element is a film capacitor, and the film capacitor includes a core rod made of a highly thermal conductive material.

8. The semiconductor device according to claim **1**, wherein:

the passive element is a film capacitor, and the film capacitor includes a carbon sheet.

9. The semiconductor device according to claim **1**, wherein:

the semiconductor element is disposed on a base substrate, and

the base substrate is disposed on the cooling member across a thermal conductive member.

10. A semiconductor device comprising:

a semiconductor module including a semiconductor element;

a passive element;

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a cooling member disposed between the semiconductor module and the passive element; and
 a first conductive member and a second conductive member for electrically connecting the semiconductor module and the passive element,

wherein the first conductive member at least includes a part with a first width and a part with a second width greater than the first width, the part with the second width being disposed between the cooling member and the passive element.

11. A semiconductor device comprising:

a semiconductor module including a semiconductor element;

a passive element;

a cooling member disposed between the semiconductor module and the passive element; and

a first conductive member and a second conductive member for electrically connecting the semiconductor module and the passive element, wherein:

the cooling member and the semiconductor module are disposed between the first conductive member and the second conductive member,

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the cooling member includes a through hole, and at least one of the first conductive member and the second conductive member extends through the through hole of the cooling member.

12. A semiconductor device comprising:

a semiconductor module including a semiconductor element;

a passive element;

a cooling member disposed between the semiconductor module and the passive element; and

a first conductive member and a second conductive member for electrically connecting the semiconductor module and the passive element, wherein:

the cooling member and the semiconductor module are disposed between the first conductive member and the second conductive member,

the cooling member includes two or more through holes, and

the first conductive member and the second conductive member respectively extend through the through holes different from one another.

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